INDOOR AIR POLLUTION
AND
HOUSING TECHNOLOGY

Prepared for
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Policy Development and Research Sector
Canada Mortgage and Housing Corporation
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FOREWORD

The sponsor of this report, CMHC, is concerned about the lack of readily available information on indoor air quality especially as it relates to Canadian building practices, habits and climate. During discussions with various federal agencies and departments and with members of the private sector, the lack of a comprehensive body of knowledge on indoor air quality became apparent. It was felt that a review of the interactions between building technology, indoor air pollution and its associated health effects would be of value to those involved in indoor air quality related activities.

In recognition of this, and as a first step in attempting to remedy the lack of readily available information on this subject, it is hoped that this document will serve that purpose. It is intended primarily to be a research-oriented literature review of existing information. As such, it serves to illustrate the extent to which prevalent building practices need to be altered to achieve a clean indoor environment. It is not to be viewed as a guide for cost effective pollution elimination and control methods.

At first glance, the report may give the impression of how much is known on the subject of indoor air quality. However, on closer examination, the deficiencies of our knowledge become more apparent. This is especially true as it relates to defining solutions rather than problems. While every effort has been made to incorporate Canadian references, the paucity of relevant Canadian research in most areas is evident.

Particular thanks are extended to Health and Welfare Canada, Public Works Canada, National Research Council, the UFFI Centre (Consumer and Corporate Affairs) and the Research Division of Canada Mortgage and Housing Corporation for their review of this report and the valuable contributions made.

The aforementioned departments are engaged in research on indoor air quality. Some individual projects are coordinated with provincial departments and with the Housing and Urban Development Association of Canada. Research projects underway or proposed address a broad range of topics, including the following:

- consolidation and dissemination of information
- identification of the nature and extent of the problems
- policy options and impacts
- development of pollutant measuring techniques and criteria for acceptable levels of pollutants
- materials science and product evaluation
- development of solutions
- guidelines for builders and householders on how to provide and maintain clean indoor air.

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ABSTRACT

This study reviews the scientific literature on indoor air pollution. Research and measurements performed primarily in the United States and Europe indicate that indoor air pollution is a common problem.

Many materials and conditions which contribute significantly to indoor air pollution are known to be present in Canadian homes. However, the number of Canadian homes in which air pollution levels present a major problem is presently unknown.

Major pollutants include carbon monoxide, nitrogen oxides, radon gas, formaldehyde, tobacco smoke, ozone, asbestos, dust and moulds, bacteria and viruses, and a host of organic chemical vapours, some of which are known or suspected carcinogens.

The study states that indoor air pollution is a total population problem and that a significant number of Canadians are in high-risk categories with respect to pollutant exposure. There is also a small but growing population of chemically susceptible persons in Canada for whom today's residential air quality levels are totally unacceptable, and who require low-pollution housing.

Low-pollution design and construction techniques employed in the author's 'Sunnyhill' Low-Pollution Research Centre are outlined in detail and suggestions are made on their applicability to new and existing housing in Canada.

The study recommends a four-fold approach to the indoor air pollution problem by government and the building industry:

A. Short-circuit major potential hazards
B. Deal with low-pollution housing needs
C. Spread and apply present knowledge
D. Foster more research and discussions on regulation

EXECUTIVE SUMMARY

The objectives of this study were a) to review the scientific literature relating to residential indoor air pollution and to low-pollution design and construction, b) to comment on the significance of indoor air pollution problems in Canada, and c) to make recommendations for further research and application of low-pollution housing techniques in Canada.

The scientific literature revealed that there are many gaps in our knowledge of the long-term effects of indoor pollutants on health. There is sufficient evidence, however, to support the following conclusions:

1) Many materials and conditions which contribute significantly to indoor air pollution are known to be present in Canadian homes.
2) Some people are more susceptible to air pollution than others, and even individual susceptibility varies over time.
3) Smoking remains a major source of indoor air pollution.
4) Some energy conserving measures aggravate indoor pollution problems.
5) The full health, social, and economic costs of indoor air pollution have yet to be determined.
6) Acceptable levels of effects on health from indoor air pollution have not been defined.

Major pollutants of key concern are carbon monoxide, nitrogen oxides, radon gas, formaldehyde, tobacco smoke, ozone, asbestos, dust and moulds, bacteria and viruses, and a host of organic chemical vapours, some of which are known or suspected carcinogens. Major sources or causes of these are faulty chimney construction and furnace operation, gas stoves, unvented kerosene heaters, wood stoves, soil gases, insulation, particleboard and home furnishings, tobacco smoking, household appliances and products, dampness, human metabolism, and widespread use of potent household chemicals including pesticides.

Tightening houses and reducing ventilation in order to conserve energy, without attention to sources of indoor pollutants, can lead to levels of contaminants indoors which are dangerous to health. Introduction of new types of insulation and sealants can also cause health problems to some people. Better techniques and materials are needed to achieve reasonable energy conservation without excessive levels of indoor pollution.

Evidence is presented which shows that tobacco smoking throughout a home is incompatible with the good health of both smokers and their non-smoking companions or family. The cost of sufficient ventilation to remove it is prohibitive. If people must smoke, use of a small specially-vented smoking area is the most efficient way to protect the health of non-smokers.

Indoor air pollution is seen as a total population problem. A significant percentage of Canadians are in high-risk categories with respect to pollutant exposure. In addition, there is now a small but growing population of chemically susceptible persons in Canada for whom present residential air quality levels are totally unacceptable. Technology and facilities necessary to meet the specialized needs of such persons should be developed, just as they have been for other physical handicaps. In order to prevent health problems in others, consumers must be educated to recognize building-related health problems and to be able to test proposed building materials and furnishings against occupant sensitivities.

Low-pollution design and construction techniques employed in the author's 'Sunnyhill' Low-Pollution Research Centre are reviewed in detail. Those most applicable to conventional housing include avoidance of major indoor pollutant sources and use of low-emission materials and furnishings, carefully sealed vapour barriers, deliberate fresh air intake and exhaust venting with heat exchange, 'spot' or 'task' venting of certain appliances and activities, use of hot water heat or heat pump, air filtration, use of vented storage cupboards and maintenance with non-volatile and non-toxic products.

The following is a 'keyword' summary of the study recommendations:

A. SHORT-CIRCUIT MAJOR POTENTIAL HAZARDS

A1. Organize inter-agency approach to alert Canadians to:

1) unlined chimneys with gas furnaces
2) unvented kerosene space heaters
3) unsealed particleboard
4) other major indoor pollution hazards

B. DEAL WITH LOW-POLLUTION HOUSING NEEDS

B1. Study need for low-pollution housing
B2. Develop prototype 'clean' housing designs
B3. Foster diagnosis and rehabilitation facilities
B4. Develop practical list of building materials

C. SPREAD AND APPLY PRESENT KNOWLEDGE

C1. Develop research contacts and produce a 'who's who'
C2. Organize an accessible information base
C3. Establish an interagency forum for discussion
C4. 'Distil' research for practical application
C5. Prepare and distribute public information in lay terms
C6. Encourage introduction of low-pollution design in housing

D. FOSTER MORE RESEARCH AND DISCUSSIONS ON REGULATION

D1. Undertake studies in low-pollution design
D2. Develop practical air quality monitoring devices
D3. Develop air quality feedback control systems
D4. Fund health research on indoor pollution effects
D5. Study socioeconomic costs of indoor air pollution
D6. Study regulatory and other control options

TABLE OF CONTENTS

Abstract i
Executive Summary iii
Table of Contents v
List of Illustrations ix
Introduction and Objectives 1

PART 1: LITERATURE REVIEW - RESIDENTIAL INDOOR AIR POLLUTION 4

1.1 Indoor Air Pollution: How The Problem is Perceived 4

1.2 Individual Indoor Air Pollutants: Their Incidence and Known Effects 6

1.2.1 Carbon Monoxide 9
1.2.2 Radon and Radon Decay Products 14
1.2.3 Nitrogen Oxides 18
1.2.4 Sulphur Dioxide 26
1.2.5 Ozone 29
1.2.6 Asbestos 33
1.2.7 Tobacco Smoke 36
1.2.8 Formaldehyde 42
1.2.9 Carbon Dioxide 48
1.2.10 House Dust and Dust Mites 50
1.2.11 Fungi (Mould and Mildew) 52
1.2.12 Bacteria and Viruses 55
1.2.13 Consumer Product Aerosols 58
1.2.14 Other Suspended Particulates 60
1.2.15 Pesticides 64
1.2.16 Ammonia 68
1.2.17 Chlorine 70
1.2.18 Various Organic Vapours 72
1.2.19 Summary Table 84

1.3 The People Affected 86

1.3.1 The General Population 86
1.3.2 Specific High-Risk Groups 90
Size of the High-Risk Population 91
1.3.3 General Chemical Susceptibility 93

1.4 Medical Unknowns 98

1.5 Cross-Index of Pollutant Sources 101

1.5.1 Improper Chimney Construction for Gas Furnaces 102
1.5.2 Gas Stoves 103
1.5.3 Unvented Gas and Kerosene Heaters 106
1.5.4 Fossil Fuel Furnaces 108
1.5.5 Wood and Coal Furnaces or Stoves 109

../continued

(continued)

1.5.6 Outgassing of Furnishings and Decorative Materials 110
1.5.7 Intrusion of Outdoor Pollutants 113
1.5.8 Use of Household Chemicals 115
1.5.9 Consumer Appliances 117
1.5.10 Spray Humidifiers 119
1.5.11 Paints and Sealers 120
1.5.12 Insulation 124
1.5.13 Occupants' Activities 126
1.5.14 Summary Table 127

1.6 Factors Aggravating Indoor Pollution 129

1.6.1 Tightening of Houses and Reduced Ventilation 130
1.6.2 Increased Humidity and Temperature 131
1.6.3 Other Factors 133

1.7 Factors Reducing Indoor Air Pollution 134

1.7.1 Increased General Ventilation 135
1.7.2 Decreased General Ventilation 140
1.7.3 Adsorption on Interior Surfaces 142
1.7.4 Gassing-out Period 143
1.7.5 Use of Low-emission Materials and Systems 144
1.7.6 Source Removal 145
1.7.7 Modification of Combustion Processes 146
1.7.8 Changes in Building Design and Construction Practices 147
1.7.9 Changes in Building Maintenance Practices 148
1.7.10 Air Filtration 149
1.7.11 Use of Sealants 151
1.7.12 Adjustment of Product Formulation 152
1.7.13 Treatment of Final Product 152
1.7.14 Ventilation of Specific Sources 153
1.7.15 Human Factor Control 154
1.7.16 Warning Devices & Controls 154
1.7.17 Summary Table 155

1.8 Summary and Interpretation of Literature Review 157

Keyword Summary of Conclusions 162

../continued

PART 2: LOW-POLLUTION DESIGN AND CONSTRUCTION 163

2.1 The Sunnyhill Example 165

2.1.1 Background and Problem Addressed 165
2.1.2 Design Principles 168

a) The Physics of Indoor Air Pollution 168
b) General Methods for Reducing Indoor Air Pollution Exposure 169
c) How the General Methods are Applied in the Sunnyhill Example 170

2.1.3 Materials and Testing Methods 174
2.1.4 Design of Features and Systems 181

a) Location 182
b) Airtight Construction Using Cavity Wall 183
c) Steel Framing and Concrete Floors 184
d) Interior Framing Separated from Vapour Barrier on Outside Wall 185
e) Deliberate Venting Through Multiple Inlets 186
f) Tempering and Filtration Of Intake Air 187
g) Recirculation of Interior Air With Filters 188
h) Passive Solar Design 189
i) Hot Water Electric Heating Source and Potential for Heat Pump and Solar Heat 190
j) Low Temperature Radiant Heat in Ceiling 191
k) Central Exhaust System 192
l) Lighting Fixtures Embedded in Ceiling 193
m) Generous Provision of Cupboards, Some Vented 194
n) Layout For Separation of Activities 195
o) Use of 'Bedroom Sanctuary' Concept 196
p) Central Vacuum Cleaner with Exterior Motor 197
q) Bare Floors Without Wall-to-wall Carpeting 198
r) Relatively Bare Furnishings 199
s) Unpainted Plaster Walls 199
t) House Rules 200

2.1.5 Construction Techniques & Supervision 201

a) Cavity wall construction 201
b) Attachment of Interior Insulation 204
c) Construction Supervision 207
d) Effect of On-Site Pollution on Construction Personnel 210

2.1.6 Effectiveness of Design 212

2.1.7 Ongoing Monitoring and Research 214

a) Monitoring of indoor and outdoor pollutants 214
b) Development of automatic control systems 215
c) Effectiveness of design for diagnosis and rehabilitation of persons with chemical susceptibilities 215
d) Testing of materials in the low-pollution environment 216

2.2 Application to Current Construction Practice 217

2.2.1 Evidence of Need 217
2.2.2 Problem Materials and Design 217
2.2.3 Energy Conservation 220

a) Addition of insulation 220
b) Addition of caulking and other sealants 220
c) Super-sealing the building envelope 220
d) Installation of air solar heating 221

2.2.4 Adaptable Techniques 221
2.2.5 Cost Implications 222

PART 3: RECOMMENDATIONS 223

Keyword Summary of Recommendation 226

Appendix 1: Full Bibliography 227
Appendix 2: Conferences and Meetings Cited 261

Index of Names 265
Index of Subjects 273

List of Illustrations

No.	Title	Page
1	Decay Chain, Radium 226 to Lead 210	14
2	Some Primary Pathways for Radon Entry	14
3	Indoor Radon Concentrations	17
4	A Time History of NO2 Concentrations	21
5	Various Organic Chemicals and Their Uses	75
6	Categories of Chemicals and Common Uses	76
7	A Time History of CO Concentrations	103
8	Pollutant Concentrations from a Kerosene Heater	107
9	Sunnyhill Low-Pollution Centre (aerial view)	166
10	Sunnyhill Low-Pollution Centre (entrance)	166
11	Sunnyhill - Ground Floor Functional Areas	167
12	Sunnyhill - First Floor Functional Areas	167
13	Sunnyhill - Second Floor Functional Areas	167
14	Comparison of Methods for Reducing Indoor Air Pollution	171
15	Interpretation of Test Reactions When Choosing Materials for Chemically Susceptible Persons	176
16	Testing Results on Principal Materials for Sunnyhill Application	177-180
17	Location of Sunnyhill Low-Pollution Centre	182
18	Cavity Wall Detail	183
19	Steel and Concrete Structure	184
20	Interior Plaster Wall	185
21	Sequence of Filtration Media in Intake and Recirculating Filters	188
22	View of Sunnyhill From Southwest Showing Solar Features	189
23	Radiant Heating Panel	191
24	Exterior Exhaust Fan	192
25	Light Fixtures Embedded in Ceiling Space	193
26	Vented Cupboard	194
27	Main Floor Detail Showing Separation of Areas	195
28	Bedroom 'Sanctuary' Concept	196
29	Steel Channel Supports under Hardwood Flooring	198
30	Sign at Entrance of the Sunnyhill Centre	200
31	Window Frame and Cavity Wall Detail	203
32	Doorway and Cavity Wall Detail	203
33	Attachment of Interior Insulation	205

INTRODUCTION AND OBJECTIVES

Until recently, interest in air pollution has focused on the outdoor environment. Efforts have been directed primarily to reducing effluents from combustion, for example, from the automobile and from industrial sources. The goal of limiting outdoor air contaminants was based on the fact that many people's health suffers when the air is not clean.

Many developments have taken place which are now shifting the focus to the indoor environment, where Canadians spend most of their time. With increased sophistication of measurement and continuing medical research, it became apparent that pollution indoors could also present a health problem. Two trends in the last decade have also made it particularly important to address the indoor air issue seriously.

First, rising energy prices and the need for secure, self-sufficient energy supplies have made Canadians aware of the need to make homes more efficient and to reduce consumption of fuel for heat. Older houses tended to leak through the many cracks around doors and windows, and pollution created inside was often flushed out relatively quickly. When older houses were 'tightened up' and new houses were built that allowed little infiltration of outside air, pollutants built up indoors, often to dangerous levels.

Secondly, many new materials have been introduced in Canadian homes. New types of insulation, composite materials, glues, sealers, and furnishings have been developed that were unheard of a generation ago. Many of these products give off small amounts of chemicals used in their manufacture, and the total of all these new materials 'gassing off' in a home began to present an air quality problem. Moreover, with new chemical exposures in the workplace, the school, and in the home, more Canadians appear to have reached their limits of adaptation to this total pollutant load.

Indoor air pollution became a household word as a result of Urea-formaldehyde Foam Insulation, which was installed in many Canadian homes and subsequently banned because of its adverse effects. 'UFFI' confirmed in a very dramatic way that people could experience severe, immediate health effects from indoor pollutants. It brought forward the fact that some individuals are more likely to be made ill by low-level air pollution than others, and that some chemical exposures can cause an otherwise healthy person to become much more susceptible to the effects of pollution in general.

In this context, and in a country like Canada where the harsh winter climate forces most people indoors for much of the time, it became imperative to look closely at the problem of indoor air pollution. It also became important for those concerned with energy conservation to begin to work together with those concerned with health, and together to meet both goals.

The objectives of this study are as follows:

1. Re: Indoor Air Pollution

   a) To review the literature and contact appropriate researchers in the building and health fields, in order to determine:

      i) whether or not there are or could be significant indoor air pollution problems in Canadian residences, and, if there are,

      ii) what is the nature of these problems, and

      iii) what are the causes and possible solutions to these problems.

   b) To present an overview of the significance of indoor air pollution problems in Canada.

2. Re: Low-Pollution Design and Construction

   a) To review the literature and contact appropriate researchers in the building and health fields, in order to determine:

      i) materials, systems and methods of construction that will achieve low indoor air pollution levels and which are also compatible with energy conservation.

   b) To document design and construction methods used to date in the author's low-pollution research facility 'Sunnyhill' at Goodwood, Ontario, northeast of Toronto, Canada.

3. Re: Further Research in Chemical Susceptibility and Residential Low-Pollution Design and Construction

   a) To make specific recommendations as to further research that should be carried out in Canada in order to address any problems reported, with particular reference to determining the extent of general chemical susceptibility among the Canadian population and application of low-pollution design techniques to new and existing housing in Canada.

This report provides a beginning to an ongoing information base, and a basis for interdisciplinary discussion about indoor air pollution problems in Canada. Readers are encouraged to contact the author at the address below if they have further technical references, research results, or personal views to offer.

The report has been written as a research document for a varied readership, including:

- officials of government departments and agencies at several levels,
- design, building research, and health professionals, and
- representatives of related manufacturing industries and building trades.

Although the study is intended to cover the full breadth of indoor air pollution issues, time and resources do not permit a detailed discussion of each area. Readers may refer to the bibliographic references for further information.

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PART 1: LITERATURE REVIEW - RESIDENTIAL INDOOR AIR POLLUTION

The following section reviews the existing literature on indoor air pollution. References are cited by author and date and are listed alphabetically by author in a full bibliography presented in the Appendix to the report.

1.1 Indoor Air Pollution: How the Problem is Perceived

The literature on indoor air pollution has developed slowly over the last three decades. At first, indoor air pollution was seen as a residual problem caused by outdoor air pollution alone. As more data was gathered it became clear that indoor pollution is created partly by sources indoors, and that for many gases and particulate contaminants, indoor concentrations exceed those outdoors, often by orders of magnitude.

In general, the following reasons have been cited for considering the presence of pollutants in indoor air to be a potentially significant problem:

1. many industrial and outdoor air pollutants in sufficient concentrations have been shown to have both short-term acute and long-term chronic health effects

2. many people spend 90% or more of their time indoors

3. specific incidents have occurred in which health problems in some individuals have been connected with the presence of indoor pollutants, for example:

    - death from carbon monoxide poisoning due to faulty chimneys exhausting gas furnaces
    - respiratory illness in homes with unvented gas stoves
    - various symptoms in mobile homes, homes insulated with urea-formaldehyde foam, and homes with large quantities of particleboard

The need to understand the exact nature and extent of the indoor problem has been made more urgent by recent moves on the part of many nations to add energy conservation features to both existing housing and new construction. The reduction of ventilation and the introduction at the same time of many new materials which are sources of indoor air contaminants are seen as leading inevitably to higher indoor air pollution levels if no action is taken.

Over the last five years there has been increasing interest in the subject in many countries, and numerous overview studies have been commissioned. The quotations on the following page are from a number of representative studies. They will give the reader an idea of the type of conclusions that have been reached, and the range of opinions that have arisen from analysis of essentially similar data with varying viewpoints.

PERCEPTION OF THE INDOOR AIR POLLUTION PROBLEM

" It was felt that adoption of current energy-saving proposals in many countries ... would aggravate existing problems of indoor air quality, create new problems and generally be detrimental to health, unless appropriate pollution control measures were taken simultaneously."

(World Health Organization Working Group, 1979)

" Indoor air pollution poses a potentially serious health hazard."

(General Accounting Office, U.S., 1980)

" For a limited number of air contaminants ... there is direct and circumstancial evidence that human exposures are large enough and common enough to account for substantial morbidity and premature mortality."

(National Research Council, U.S., 1981)

" Some recent studies ... have shown that increased indoor pollutant levels lead to increased health risk. Such work experimentally confirms the notion that indoor sources emit sufficient quantities of some pollutants to harm occupants in the absence of sufficient ventilation."

(Dudney & Walsh, for US Dept. of Energy, 1981)

"Reduced ventilation in buildings may significantly increase exposure to indoor air pollution and perhaps have adverse effects on occupant health and comfort."

(Hollowell, Lawrence Berkeley Laboratory, 1981)

"There is increasing evidence that many modern buildings are damaging the health of the people who live and work in them. Building design changes intended to conserve energy, new materials used in construction, and the presence indoors of numerous hazardous substances are combining to make this indoor environment, where most Americans spend 90 percent of their time, an unhealthy place."

(California Department of Consumer Affairs, 1982)

1.2 Individual Indoor Air Pollutants: Their Incidence And Known Effects

The major reviews of indoor air pollution generally agree as to what pollutants or pollutant sources represent the major components of the indoor air problem.

The following air contaminants are seen as having either "important known" or "reasonably likely" effects (National Research Council U.S., 1981, p. II-8, Hollowell, 1981 p. 3, and Traynor et al, 1981):

sidestream cigarette smoke
radon gas and radon decay products
mineral and vitreous fibers (e.g. asbestos)
formaldehyde
indoor combustion products (e.g carbon monoxide, carbon
    dioxide, nitric oxide, nitrogen dioxide,
    sulphur dioxide, formaldehyde and respirable
    particulates)
agents of indoor contagion (bacteria, viruses, fungi)
allergens (moulds, dust, danders)

Another group of contaminants could present a problem but the reviews indicated in general that evidence was less conclusive at this time than for those above:

consumer product aerosols
pollutants from hobbies, interior decorating
    and maintenance (e.g. solvents and pigments)
outgassing from various building materials
outgassing from various home appliances
metabolic products from occupants
intrusion from outdoor pollutants
ozone (e.g. from an electrostatic dust precipitator)
pesticides

The incidence and health effects of individual gases and particulate contaminants will be reviewed one by one in this section. Section 1.5 "Pollutant Sources" will cross-reference these pollutants by source. Where possible, concentrations of contaminants will be compared to present ambient air or indoor air quality standards in Canada and/or the United States.

To provide some context in which the reader may view the following pollutant summaries, it should be mentioned that so-called normal or clean outdoor air contains a veritable 'soup' of natural chemicals and dusts, and it is this atmosphere in which human beings evolved. Natural sources are therefore included along with man-made sources in the summary for each air contaminant. The table on the next page gives the natural constituents of 'clean air' (Waldbott, 1973).

CONSTITUENTS OF NATURAL 'CLEAN' OUTDOOR AIR*

1. major gases in the following proportions (in dry air):

Oxygen (O_2)	20.94%
Nitrogen (N_2)	78.09%
Argon (Ar)	0.93%
Carbon Dioxide (CO_2)	0.03%
other gases	0.01%
	100.0 %

2. water vapour: representing 1% to 4% by volume of the total air mixture

3. aerosols (clouds of particles or liquid droplets suspended in gas) of two types:

   - neutral particles such as dust and fumes, ranging in diameter from 0.1 to 30 microns (these tend to precipitate and settle on the ground). (1 micron = 10^{-6} metre)

   - condensation nuclei, made of up hygroscopic (moisture-attracting) substances, ranging in diameter from 0.01 to 0.1 microns. Natural sources of such nuclei are volcanic eruption, meteoric dusts, natural radiation, organic decay, and sea spray

4. various particles from insects

5. dusts from streets and fields

6. tree, grass, and weed pollens

7. fungus and mould spores

8. decaying plant and animal matter

9. bacteria and viruses

10. gases from marshes and soils

11. odours from animal and human secretions

12. organic gases such as ketones, hydrocarbons, and aldehydes from green plants as a result of photochemical action (such volatile organic products often create extensive haze, e.g. when released from forests on hot days)

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* (derived from Waldbott, 1973)

Sub-Index of Individual Pollutant Summaries

The following sections review the scientific literature on each major indoor air pollutant individually, giving a brief description, major sources, the range of concentrations, standards, incidence, and health effects associated with each pollutant. Where applicable an additional discussion section is included.

The text is confined to major points relevant to residential indoor air pollution and is intended as a basis for discussion rather than as an exhaustive treatment. Further references from readers will be welcomed.

The problems of determining the health effects and significance of any individual air pollutant are complex, and the information provided herein can only be expected to provide a beginning to the process. Readers might wish to keep in mind the following summary, presented by Olishefski (1981, p. 518) in his treatise entitled "Fundamentals of Industrial Hygiene":

> "It is important to recognize that the toxicity of a substance is not necessarily the most important factor in determining the extent of a health hazard associated with the use of that material. The nature of the process in which that material is used or generated, the possibility of reaction with other agents (physical or chemical), the degree of effective ventilation control, the extent of enclosure, and the duration of exposure all relate to the potential hazard associated with the use of that material. Consideration should also be given to the type and degree of toxic response the material may elicit in both the average and the hypersusceptible person".

	page
1.2.1 Carbon Monoxide	9
1.2.2 Radon and Radon Decay Products	14
1.2.3 Nitrogen Oxides	18
1.2.4 Sulphur Dioxide	26
1.2.5 Ozone	29
1.2.6 Asbestos	33
1.2.7 Tobacco Smoke	36
1.2.8 Formaldehyde	42
1.2.9 Carbon Dioxide	48
1.2.10 House Dust and Dust Mites	50
1.2.11 Fungi (Mould and Mildew)	52
1.2.12 Bacteria and Viruses	55
1.2.13 Consumer Product Aerosols	58
1.2.14 Other Suspended Particulates	60
1.2.15 Pesticides	64
1.2.16 Ammonia	68
1.2.17 Chlorine	70
1.2.18 Various Organic Vapours	72
1.2.19 Summary Table	84

1.2.1 Carbon Monoxide

Description:

Carbon monoxide (CO) is a relatively stable reaction product of the incomplete combustion of fossil fuels (produced when there is insufficient oxygen present due to improper mixing of air and fuel during combustion) (Young, G.S., 1981, p. 2-1). Carbon monoxide is colourless, odourless and tasteless, and is not readily perceived by the human senses. This latter fact helps explain the subtle hazards associated with this non-irritating gas (Hackney, 1974, p. 92).

Major Sources:

The major outdoor source is automobile exhaust, although stationary sources such as industrial and public utility chimneys also contribute to outdoor and therefore indoor CO levels (Hollowell, 1981, p. 4).

Major indoor sources are gas ovens, stoves and furnaces, cigarette smoking, gas-fired water heaters, gas or kerosene-fired space heaters, fireplaces, and spills on heating elements (Brookman & Birenzvige, 1980, and Traynor et al, 1981). Oil heaters and furnaces have also caused problems. Ott and Flaschbart (as reported by Raloff, 1981) cite basement parking garages in apartments and office buildings as a potential source of carbon monoxide pollution. Similarly, garages in or attached to single-family dwellings or row houses can introduce carbon monoxide and other pollutants into living spaces.

Concentration Range:

Typical average indoor CO concentrations in residences vary between 0.5 and 5 ppm (600-6000 mcg/m^3) (National Research Council U.S., 1981, p. II-3). Peaks in some homes with gas stoves exceed 100 ppm (120,000 mcg/m^3) . (ppm = parts per million; mcg/m^3 = micrograms/cubic metre)

Standards:

Canadian Ambient Air Quality Standards for Carbon Monoxide (from Statute Revision Commission, 1978a):

	desirable range (in mcg/m^3)	acceptable range (in mcg/m^3)
average over eight hours	0 to 6,000	6,000 to 15,000
average over one hour	0 to 15,000	15,000 to 35,000

United States (from Young, G.S., 1981, pp. 2-10ff
and Traynor et al, 1982, p.2):

	ppm	mcg/m^3
1. eight-hour ambient standard (US EPA):	9	10,000
2. one-hour ambient air quality standard (US EPA):	35	40,000
3. OSHA Permissible Exposure Limit (PEL) for 8-hr time-weighted average (TWA):	50	56,000
4. 15-minute American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value - Short Term Exposure Limit (TLV-STEL):	400	450,000

Incidence:

Yocom, Cote & Clink (1970) reported measurements over a 48-hr. period in one split-level home varying from 0.5 ppm to just over 5 ppm. The highest levels corresponded to cooking times with a gas stove and times at which a car was driven into or out of an attached garage. Lower peaks followed increases in the ambient outdoor concentrations. Levels in different rooms sometimes differed by a factor of 2 (as reported by Brookman & Birenzvige, 1980).

Sterling et al (1981) state that the average carbon monoxide level measured in city houses near medium-sized thoroughfares is approximately 6 to 7 ppm. Sterling and Sterling (1979) measured carbon monoxide levels in the kitchens of nine homes in Burnaby, British Columbia, after 20 minutes of cooking with a gas stove. The carbon monoxide levels varied from a low of 34.5 ppm to a high of 120 ppm.

Lawrence Berkeley Laboratory experiments involving a gas stove operating inside a monitoring chamber showed that CO levels approached 50 ppm after the oven had been on at 180 degrees C (350 F) for one hour, under 'tight' conditions of .24 air changes per hour. At one air change per hour the concentrations were within the 35 ppm one-hour United States (EPA) air quality standard (Hollowell and Traynor, 1978, p. 7).

Traynor et al (1982) measured emissions from radiant and convective type portable kerosene heaters, in a 27 m^3 environmental test chamber with an air exchange rate of 0.4 per hour. CO levels from the radiant type heater reached approximately 12 ppm, exceeding the U.S. Environmental Protection Agency's 8-hour outdoor standard of 9 ppm. Levels from the convective type reached approximately 3 ppm.

Reviews by the U.S. National Research Council (1981 p. I-8) and by Young (1981, pp. 2-10ff) reported similar levels, with peak concentrations of carbon monoxide up to 100 ppm in some cases. In one kitchen measurement a level of 4.5 ppm CO was found even with just the gas pilot burning.

Although no measurements have been reported some concern has also been voiced over emissions of gas stoves during self-clean cycles.

Health Effects:

Griffin (1974, p. xxi) states that the effects of carbon monoxide stem from its propensity to interfere with oxygen transport in the body by displacing oxygen from hemoglobin and other proteins. That is, it reduces the capacity of the blood for carrying oxygen, which is needed by body tissues. This propensity is so constant that an equation can be developed to describe the relationship between the concentration of inspired carbon monoxide and the resultant blood carboxyhemoglobin (COHb) at equilibrium. Calabrese (1978b, p. 306) states that while oxygen combines somewhat more quickly with hemoglobin as compared to carbon monoxide, the strength of the bond between carbon monoxide and hemoglobin is approximately 200-300 times greater than that of oxygen.

Carboxyhemoglobin levels (in percent COHb of total hemoglobin) at equilibrium associated with different inspired CO levels (in non-smokers) are quoted by Coburn et al (1965, as reported in Hackney, 1974):

Inspired CO (ppm)	%COHb
0	0.36
5	1.11
8.7	1.66
10	1.85
15	2.57
20	3.29
30	4.69
35 (US EPA 1 hr. standard)	5.0
40	6.05
50	7.36

Hexter and Goldsmith (1971) found a significant association between community carbon monoxide concentrations and mortality in Los Angeles County, California. They estimated that there were 11 excess deaths per day attributable to increased carbon monoxide levels, when average CO concentrations were at a high of 20.2 ppm, compared to the number of deaths on a day when CO concentration was at a low of 7.3 ppm. During the study there were an average of 160 deaths per day in the area considered.

The most sensitive measures that detect the effects of carboxyhemoglobin concentrations fall into three categories: (Griffin, 1974)

a. Effects on vigilance: Carboxyhemoglobin concentrations in the range of 3% to 5% may degrade the ability to detect small unpredictable environmental changes.

b. Effects on exercise: Concentrations as low as 5% will decrease maximal oxygen consumption during exercise in healthy young males.

../list continued

c. Exacerbation of symptoms in patients with cardiovascular disease: Patients with exertional angina pectoris develop chest pain earlier in the course of exercise at COHb concentrations of 2.5% to 3.0% than at 1%. Further, COHb concentrations of 3% have hastened the onset of leg pain during exercise in patients with peripheral arteriosclerosis. (The COHb concentration at equilibrium associated with exposures to CO at the U.S. EPA one-hour standard of 35 ppm is about 5%.)

Hackney (1974) suggests that individuals with cerebral vascular disease and potential reduction in the supply of oxygen to higher cerebral centers may be another group susceptible to high levels of CO. In such cases, small amounts of COHb could have disproportionately severe effects on higher cerebral function (cerebral activity, vigilance and functional capability). Cerebrovascular arteriosclerosis is prevalent among older age groups.

DeBias (1974) reported demonstrable ECG effects on the myocardium at 100 ppm CO in normal monkeys and in monkeys with myocardial infarction. His own experiments showed that the blood COHb levels of monkeys exposed continuously to 100 ppm CO for six hours reached 9.3% (+/- 1.8). The susceptibility of both normal and infarcted monkeys to ventricular fibrillation was increased with exposure to carbon monoxide at this level.

Stewart et al (1970) conducted human exposure experiments with healthy, male volunteers 24 to 42 years of age, demonstrating that carbon monoxide levels even up to 100 ppm for eight hours did not produce impairment of performance in a variety of tests on vision, hearing, coordination, reaction time, etc.

Their data on absorption and excretion of carbon monoxide, displayed in the accompanying diagram, illustrate the rise and fall of blood carboxyhemoglobin levels, and show a maximum saturation level of 11 to 13% COHb during the 100 ppm exposure. The first consistently present symptom of illness was the onset of headache as the COHb level rose from 15% to 20%, and both subjective and objective signs of CO intoxication occurred at levels above 20%.

The authors caution that since the experiments involved a select group of healthy subjects the results did not negate the conclusions of other researchers that adverse effects could be detected in some persons at significantly lower levels. They noted too that a severe headache typical of CO intoxication was delayed in one subject, leading to some concern that even a potentially lethal concentration of CO over a period of a few hours might occur without producing any warning signs.

The importance of carbon monoxide in the ambient air lies principally in the ability of CO to combine with hemoglobin (Hb). The portion of the hemoglobin present in this combined form, carboxyhemoglobin (COHb) cannot itself combine with oxygen or carry oxygen from the lungs to the rest of the body tissues. If a normal nonsmoking person were to breathe air completely devoid of carbon monoxide, he would have about 0.4% COHb in his blood, the result of a balance between internal CO production from the normal rate of red cell destruction, and the oxidation of CO in the body to carbon dioxide (CO2) or elimination of CO through the lungs. When there is CO in the ambient air, the COHb concentration increases in proportion to it. (National Research Council, U.S., 1969, p. 3)

National Research Council (U.S.) (1969, pp. 4-6) concludes that mental performance can be impaired by blood COHb concentrations as low as 2%, probably due to the interference with oxygen delivery to the brain. It notes that people appear to be able to tolerate some increase of CO concentrations in ambient air, but at the cost of some reserve capacity for oxygenation. To some extent the body adapts, but in a manner that imposes a continuing burden on physical reserves. Susceptible populations may include persons with diseases such as emphysema, pregnant women, and persons with peripheral or coronary vascular disease.

The Council quotes a study in which it was determined that the mortality rate among patients with myocardial infarction who reached a hospital was higher in weeks during which the ambient CO level exceeded 10 ppm. Exposure to CO concentrations for relatively short periods, such as 1 or 2 hours, were considered innocuous because of the delay time for buildup of COHb in blood, and it was emphasized that it is the blood level, not the concentration breathed at any moment, that counts.

Smokers who average a pack of cigarettes a day and inhale the smoke have blood COHb levels of approximately 5%. The Council concludes that the CO present in cigarette smoke could, independently of other consitituents of the smoke, produce some adverse health effects.

Since several building conditions can result in extremely high concentrations of indoor carbon monoxide (e.g. blocked chimney, car running in closed attached garage) it is important to note that concentrations above 0.1% CO in air (1000 ppm) can produce severe headache, dizziness, nausea, coma, respiratory paralysis, and death. If a person exposed to high levels survives, numerous neurological changes due to lack of oxygen may occur that may persist for weeks or even years. These can include neuritis, severe pain of the lower extremities, disturbance of speech, complete or partial loss of vision or hearing, loss of taste and smell, dizziness, headaches, amnesia, and manic or depressive psychoses (Henkin, 1974, p. 198).

Discussion:

Lawrence Berkeley Laboratory researchers have found carbon monoxide levels from indoor combustion sources often approaching or exceeding ambient air-quality standards either adopted or proposed in the United States and other countries. They conclude that "such high levels are clearly unacceptable in terms of human health, safety, and comfort, and are of particular concern in energy-efficient structures where infiltration is reduced." (Hollowell, 1981, p. 5)

1.2.2 Radon and Radon Decay Products

Description:

Radon-222 is an inert, radioactive, naturally occurring gas which is part of the uranium-238 decay chain. Any substance that contains radium-226, the precursor of radon, is a potential radon source. Radon has four short-lived 'daughters', each with a half-life of less than 30 minutes: Po-218, Po-214, Pb-214, and Bi-214 (Po = Polonium, Pb = Lead, Bi = Bismuth). These four radioactive daughter products are not inert, and most attach themselves by chemical or physical means to airborne particulates (Hollowell, 1981, p. 7, and Nazaroff et al, 1981, p.4).

Major Sources:

The major sources of radon gas affecting residential buildings are rock and soil outdoors and beneath a building, construction materials such as concrete and brick, groundwater, municipal, spring or well-water supply, and natural gas (National Research Council, U.S., 1981, p. ES-5, and Hollowell, 1981, p. 4,6).

Primary pathways of entry of radon into a building include air flow through foundation cracks (wall and floor slab) and floor/wall joints where slabs may have separated from the wall, diffusion from within the concrete itself, and air flow directly from the soil through weeping tiles into floor drains and around loose-fitting pipes. (Hollowell, 1981, p. 11)

Budnitz et al (1979) also point out that infiltration caused by wind can carry radon in high concentrations from pore spaces of building materials and soil into the house. A drop in barometric pressure can also force more radon gas into the building interior from soil and building materials.

In some homes additional radon is injected into the air by radium-containing heat storage media (e.g. rocks). Radon from springs or well-water enters indoor air when tap water flows in sinks, showers, etc. (Fleischer et al, 1981).

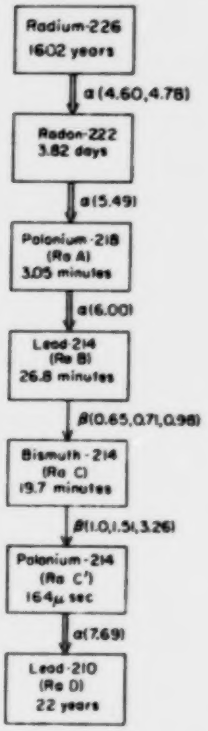
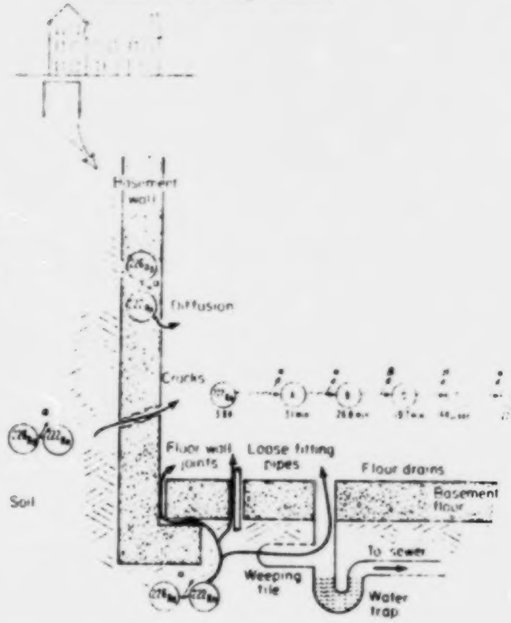

Radium-226
1602 years
α(4.60,4.78)
Radon-222
3.82 days
α(5.49)
Polonium-218
(Ra A)
3.05 minutes
α(6.00)
Lead-214
(Ra B)
26.8 minutes
β(0.65,0.71,0.98)
Bismuth-214
(Ra C)
19.7 minutes
β(1.0,1.51,3.26)
Polonium-214
(Ra C')
164μ sec
α(7.69)
Lead-210
(Ra D)
22 years

Figure 1. Decay Chain, Radium 226 to Lead 210. (Budnitz et al, 1979)

Figure 2. Some Primary Pathways for Radon Entry in Residences (Budnitz et al, 1979)


Basement wall
Diffusion
Cracks
Floor wall joints
Loose fitting pipes
Floor drains
Basement floor
Soil
To sewer
Weeping tile
Water trap

Bruno (1981) estimates that typical soils contain 1 pCi/g of radium-226 (pCi/g = Pico-Curie per gram), and that the rate at which radon is created in the soil is typically about 0.015 atoms per second per cubic centimetre of soil. Soil gas measurements have yielded concentrations of radon in soil ranging from a few hundred nCi/m^3 (nCi/m^3 = Nano-Curies per cubic metre) to several thousand nCi/m^3, depending on variations in radium content, porosity, and other factors.

Concentration Range:

A review by the U.S. National Research Council (1981, pp. I-8, II-1) reported that typical average concentrations indoors measured in U.S. homes ranged from 0.1-30 nCi/m^3 indoors or 0.004 to 0.02 WL*.

> *WL = Working Level, a measure of the potential alpha-energy concentration, a unit established initially for application to exposure of mineworkers to radon daughters. One WL is defined as any combination of radon daughters in one liter of air such that the decay to lead-210 will result in the ultimate emission of 130,000 MeV of alpha energy . This unit is insensitive to the degree of radioactive equilibrium existing among the airborne daughters and radon. If radon and its first four daughters are in radioactive equilibrium, 100 nCi/m^3 of radon implies 1 WL. In well ventilated air, where the daughters have not reached secular equilibrium, somewhat more than 100 nCi/m^3 are necessary to generate 1 WL. An equilibrium fraction of about 0.5 has been measured in both New York and Swedish homes. Lawrence Berkeley Laboratory has assumed for its purposes that 200 nCi/m^3 of radon yields 1 WL (Hollowell, 1981, p. 8 and Budnitz et al, 1979, p. 211).

Standards:

The maximum permissible concentration under present United States health guidelines is 4 nCi/m^3, or 0.02 Working Levels (WL). These health guidelines were established for houses built on reclaimed land in Florida and for houses in four communities associated with uranium mining in Canada (U.S. General Service Administration (1979), and Atomic Energy Control Board of Canada (1978) as reported in Hollowell, 1981, p. 8).

Incidence:

McGregor et al (1980) measured radon and radon daughters in a total of 9999 homes in 14 Canadian cities. The geometric means of the different cities varied from 0.14 to 0.88 nCi/m^3 for radon and 0.0009 to 0.0036 Working Levels for radon daughters. About 64% of all the homes had radon concentrations of 1 nCi/m^3 or less, and about 95% had radon daughter concentrations of 0.1 Working Levels or less. The highest concentration of radon found was 75 nCi/m^3 measured in St. Lawrence, Newfoundland, and the highest concentration of radon daughters was 0.233 Working Levels, in Sherbrooke, Quebec.

Alter (1981) reports that in measurements of over 25,000 homes in a number of studies of radon concentrations in the U.S., Sweden and Canada, 15% of homes had average concentrations in excess of 20 nCi/m^3 or 0.1 WL. Those having highest concentrations were in the northeastern U.S. in areas having 'uraniferous geology' during winter months when houses are sealed more tightly, and in winter months in Sweden in areas where geology and particular construction materials were suspected of contributing to radon concentrations.

Nero and Nazaroff (1981) report that there is a wide variation in indoor concentrations of radon in U.S. homes, and that millions of the U.S. population are exposed to concentrations 10 times the average concentration. The concentrations do not correlate well with infiltration rates, and the variation in magnitude of the radon sources appears to explain the wide variation in resultant indoor air concentrations. They note that radon emanation rates from building materials such as concrete do not account for the source magnitudes calculated from indoor measurements. However, radon flux from soil averages ten times as much as that from concrete, and could account for the source magnitudes observed. They conclude that a significant proportion of the U.S. population is subject to unusually high risks.

Fleischer et al (1981) report a significantly greater concentration of radon in energy-efficient homes than in more conventional homes. Levels in first and second floor areas of the energy-efficient homes were three times those of the conventional homes in the winter, and over twice the level of conventional homes in the summer.

Budnitz et al (1979) note a New York/New Jersey area study in which the geometric mean of the annual average radon concentration on the first floor of 21 homes was 0.83 nCi/m^3, or five times the comparable outdoor level of 0.18 nCi/m^3. They also describe an Austrian study where geometric mean radon concentrations of several hundred sites were 0.42 nCi/m^3 indoors, compared to 0.16 nCi/m^3 outdoors.

Health Effects:

Respirable particulates to which radon daughter products are attached may be inhaled and retained in the tracheobronchial and pulmonary regions. Subsequent decays result in a radiation dose to those tissues. The primary health hazard is associated with the alpha emissions of polonium-218 and polonium-214. Since alpha particles have a very short range (a few tens of microns in tissue), essentially all of their energy is deposited near the surface of the lung tissue (Budnitz et al, 1979,p. 209).

Analyses of health risk assume a "linear hypothesis" model whereby the risk is directly proportional to dose. One such model predicts that exposure to an average concentration of 1 nCi/m^3 of radon would add a risk of 50 to 110 cases of lung cancer per million of population per year. This would mean a total of 2000-20,000 lung cancers per year in the United States under present typical radon exposures in homes (Hollowell, 1981, p. 5).

Discussion:

Radon and its alpha-particle emitting decay products contribute a major portion of the biologically significant dose associated with natural background radiation. The concentrations found indoors are often an order of magnitude greater than those found outdoors. Concentrations in the air are affected by ventilation rate, rate of deposition of radon progeny on indoor surfaces, and interactions of radon progeny with house dust and other airborne particles. (National Research Council, U.S., Research Council, U.S., 1981, pp. ES-5, II-1). A decrease in atmospheric pressure will increase radon exhalation from soil and from concrete walls (McLaughlin and Jonassen, 1978). (See also Section 1.7.10 "Filtration" and Jonassen, 1981a-e, 1982.)

In contrast to Nero and Nazaroff (1981), the Lawrence Berkeley Laboratory has determined that there is a correlation between indoor radon concentrations and air exchange rates. An air exchange rate of 0.5 air changes per hour was found to be required in order to maintain radon concentrations in test homes below 4 nCi/m^3, which is the maximum permissible concentration under U.S. guidelines (see Figure 3 below). The radon daughter working level followed the same general dependence on ventilation as was observed for radon concentration (Hollowell, 1981, p. 8,12).

Budnitz et al (1979) note that in Denmark, Finland, Norway and Sweden concern about high radon levels has led to a recommended minimum ventilation rate standard of 0.5 air changes per hour in residential buildings.

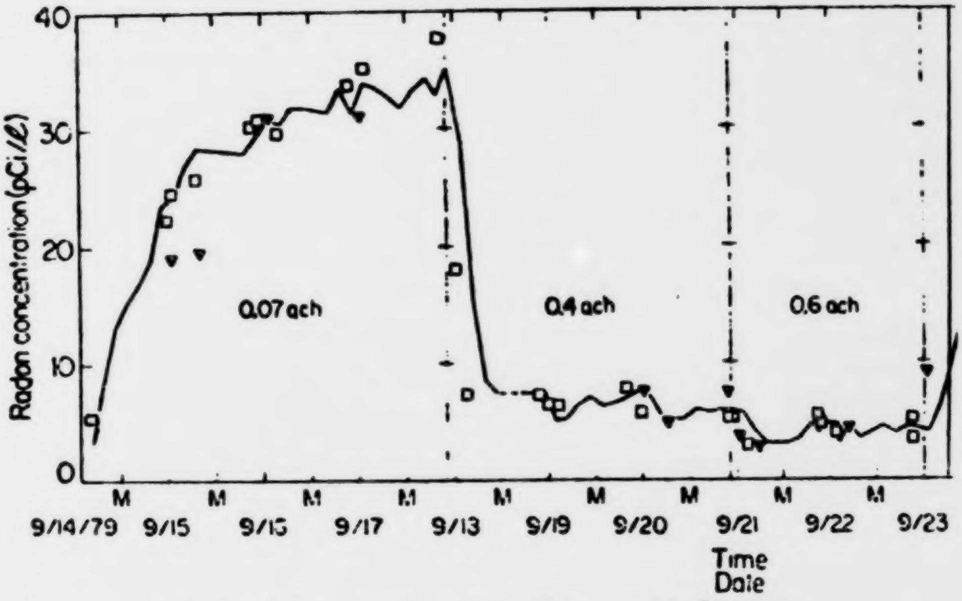


Figure 3. Indoor Radon Concentrations (in pCi/l = nCi/m^3) in an Energy-Efficient House under Three Different Ventilation Conditions, as Measured by Continuous Monitoring and by Grab Sampling (Hollowell, 1981, p.12).

1.2.3 Nitrogen Oxides

Description:

Nitrogen Dioxide is a reddish-brown, highly toxic and irritating gas with a pungent odour. In sufficient concentrations in urban situations it reduces visibility and changes the colour of the horizon. (Waldbott, 1973, p. 84)

Major Sources:

Part of the concentration of nitrogen oxides (NOx) in the atmosphere occur naturally. Nitric oxide (NO) is the major portion of the natural NOx emission and is produced by bacterial action, particularly during rainy periods. Nitric oxide is usually oxidized to nitrogen dioxide (NO2) (Waldbott, 1973, p. 84).

Outdoor combustion sources such as motor vehicles and industrial furnaces produce nitric oxide by reaction with molecular nitrogen (N2) and oxygen (O2) at 1000 degrees Celsius or more. Nitrogen dioxide is produced by oxidation of nitric oxide after mixing with ambient air (Young, G.S., 1981, p. 2-1).

Indoors the major sources of nitrogen oxides are tobacco smoking, gas cooking appliances, gas or kerosene-fired space heaters, gas-fired water heaters, wood and coal-burning stoves, indoor venting of gas dryers, cigarettes, and automobile exhaust from attached garages (National Research Council U.S., 1981, p. ES-8, Hollowell, 1981, p. 4, and Traynor et al, 1981, p.3). The percentage of nitric oxide is highly variable depending on the design features of the combustion apparatus and its method of operation (Young, G.S., 1981, p. 2-1).

Concentration Range:

Nitrogen dioxide (NO2) concentrations indoors range from 100-530 ppb, or 200-1000 mcg/m^3 (National Research Council U.S., 1981, p. I-8). (ppb = parts per billion; mcg/m^3 = micrograms per cubic meter).

Hourly average levels of nitric oxide (NO) found indoors in U.S. residences range from 30 to 300 ppb, with a maximum level reached of 500 ppb. Hourly average nitrogen dioxide (NO2) levels range from 50 to 500 ppb, with peak concentrations to 700 ppb. Weekly average indoor NO2 concentrations range from 20 to 100 ppb. The upper values were all associated with unvented gas appliances. (National Research Council U.S., 1981, p. II-4)

Girman et al (1982, p. 11) conducted experiments with unvented kerosene space heaters, which indicated that NO2 emissions are high enough to warrant concern even under relatively high ventilation conditions (see Section 1.5 "Unvented Gas and Kerosene Heaters").

Standards:

Canadian Ambient Air Quality Standard for NO2 (from Statute Revision Commission, 1978b):

	desirable range		acceptable range	
	(mcg/m^3)	(ppb)	(mcg/m^3)	(ppb)
average over one hour	—	—	0 to 400	0 to 220
average over 24 hours	—	—	0 to 200	0 to 110
annual arithmetic mean	0 to 60	0 to 32		

Ontario (from Hollowell and Traynor, 1978, p. 6):

1. one-hour average, ambient air, NO2:	200 ppb
2. 24-hour average, ambient air, NO2:	100 ppb

United States (from Young, G.S., 1981, p. 2-10ff):

1. California hourly average, NO2:	250 ppb
2. Colorado hourly average, NO2:	100 ppb
3. OSHA: PEL (Permissible Exposure Limit) as 8-hour time-weighted avg., NO2 :	5 ppm
proposed ceiling standard over 15 min.:	1 ppm
4. US EPA ambient air quality, NO2 annual arithmetic mean:	50 ppb

Netherlands (Dutch Public Health Council proposed NO2 Standards from Lebret et al, 1981):

	mcg/m^3	ppb
1-hr average not to be exceeded during 98% of time:	135	73
1-hr average not to be exceeded more than once per year:	300	160
24-hr average not to be exceeded during 98% of time:	120	65
24-hr average not to be exceeded more than once per year:	150	80

Other jurisdictions recommended or promulgated (from Hollowell and Traynor, 1978, p. 6):

Japan:	24-hour standard (promulgated)	20 ppb
West Germany:	short-term exposure (promulgated)	150 ppb
WHO/UNEP*:	one hour standard (recommended)	100-170 ppm

*(WHO/UNEP = World Health Organization/ United Nations Environmental Program)

Incidence:

Barton (1981) reports that the average of annual mean outdoor nitrogen dioxide concentrations for 34 Canadian cities was 26 ppb in 1979. Some 90% of the cities had levels below 34 ppb (the maximum desirable level under Canadian standards is 32 ppb).

The outdoor atmospheric concentrations in nonurban regions in the United States average about 8 mcg/m^3 (4 ppb) for nitrogen dioxide (NO2) and 2 mcg/m^3 (2 ppb) for nitric oxide (NO). In urban areas, outdoor nitrogen oxide concentrations are 10 to 100 times higher (Robinson, 1970). Peak concentrations of NO2 in urban areas rarely exceed 940 mcg/m^3 (500 ppb) (Waldbott, 1973, p. 85).

In a city the nitrogen dioxide levels follow a regular pattern dependent on motor traffic and sunlight. Nitric oxide levels rise shortly after dawn. Nitric oxide is converted to nitrogen dioxide throughout the day when exposed to ultraviolet radiation from the sun, reaching a peak of NO2 in the late afternoon, when nitric oxide levels again begin to rise (Waldbott, 1973, p. 85).

Hollowell and Traynor (1978, p. 5) reported that nitrogen dioxide levels in kitchens of houses with gas stoves were observed to be as high as 1000 mcg/m^3 (540 ppb) with one top burner operating for less than 30 minutes, and as high as 1700 mcg/m^3 (900 ppb) with the oven operating for 20 minutes. In experiments with a gas oven operating for one hour at 180 degrees C (350 F) in a monitoring chamber, nitrogen dioxide levels exceeded the recommended 1 hr U.S. air quality standard of 400 ppb even at 2.5 air changes per hour. They note as well that experiments with the top burners of gas stoves also show high levels of NO2, even under well-ventilated conditions.

Wade, Cote and Yocom (1975, p. 939) found that normal gas stove operations resulted in NO2 concentrations in kitchens which averaged over 100 mcg/m^3 (55 ppb) over a two week sampling period.

Hollowell and Traynor (1978, p. 5) also report that concentrations of nitrogen dioxide (NO2) were observed to be as high as 1200 mcg/m^3 (650 ppb) for 8 hours in the bedroom of a house with a forced-air gas-fired heating system operating under normal conditions.

Speizer et al (1980, p. 5,6) in a study of population exposure to indoor nitrogen dioxide in six U.S. cities showed that 24-hr. integrated average NO2 levels in homes with gas cooking significantly exceeded those in homes with electric stoves. The geometric mean levels of NO2 in gas stove homes were greater by factors ranging from 1.2 in one city to 4 in another, and varied from 14.7 mcg/m^3 to 54.3 mcg/m^3 (8 - 30 ppb). The corresponding range for electric stove houses (geometric mean levels) was 3.6 mcg/m^3 to 41.43 mcg/m^3 (2 - 23 ppb). In some houses with gas stoves the daily 24-hour levels exceeded 100 mcg/m^3 (55 ppb), the U.S. federal standard for the annual average of the 24-hour NO2 levels, but for most, levels were well below this. Peak kitchen levels reached 1100 mcg/m^3 (600 ppb) for a short period of time associated with use of a gas oven, and over 500 mcg/m^3 (270 ppb) when a single gas burner was on.

Wade, Cote and Yocom (1975, p. 939) found that normal gas stove operations resulted in NO2 concentrations in kitchens which averaged over 100 mcg/m^3 (55 ppb) over a two week sampling period (see Figure 4 below).

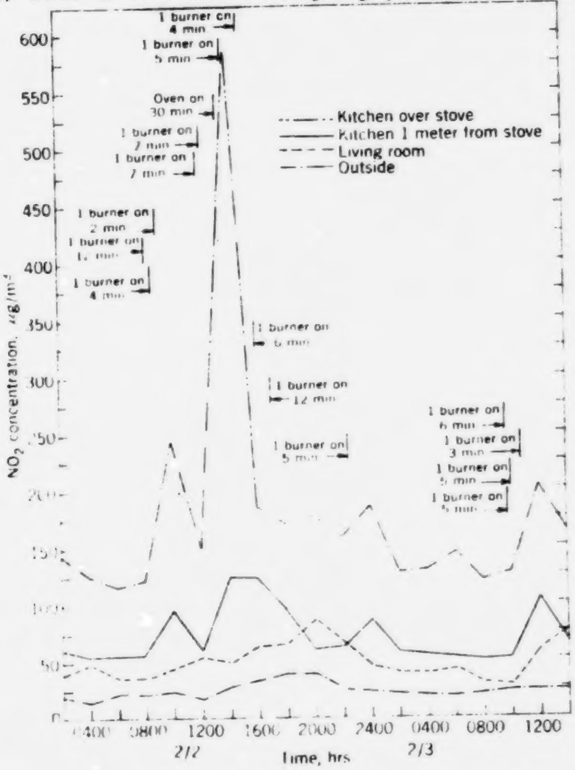


Figure 4. A Time History of NO2 Concentrations, 2 Hr. Averages, one House (from Wade, Cote and Yocom, 1975, p. 938)

Lebret et al (1981) reported a study of NO2 levels from gas-cooking and water-heating appliances in the Netherlands, in which indoor levels of NO2 were 2 to 3 times higher than the outdoor levels. The mean weekly average NO2 concentrations in kitchens was 118 mcg/m^3 (65 ppb) with a range from 35 to 472 mcg/m^3 (20 - 250 ppb). Many of the measurements exceeded the indoor NO2 standards proposed by the Dutch Public Health Council (see Standards, above).

Melia, Florey et al (1980) found higher NO2 levels in kitchens with gas stoves compared to the levels in those with electric stoves. Levels in the gas kitchens ranged from 5 to 317 ppb (mean 112.2 ppb +/- 2.7 ppb). Those in the electric kitchens ranged from 6 to 118 ppb (mean 18.0 +/- 2.4 ppb). The corresponding outdoor concentrations ranged from 14-24 ppb, with a mean of 18.5 +/- 2.0 ppb. Bedroom measurements also varied for the two types of homes, yielding a mean NO2 level of 13.9 ppb +/- 2 ppb for homes with electric stoves compared to a mean of 30.5 ppb +/-2.6 ppb in homes with gas stoves.

Traynor et al (1982, p. 2) studied NO2 levels in a 27 m^3 test chamber from convection and radiant type portable kerosene-fired heaters. Levels exceeded the California 1-hour standard of 0.25 ppm by a factor of 7 for the convective heater (approx 1.8 ppm) and a factor of 2 (approx 0.5 ppm) for the radiant model.

Indoor concentrations of nitrates range from 1.0 to 5 mcg/m^3, and are usually around 1 mcg/m^3. Their levels are typically low and usually driven by outdoor concentrations, although there are indoor sources including cooking and heating fuels. (National Research Council U.S., 1981, p. II-6)

Health Effects:

Nitrous oxide is known to produce pain, burning and choking sensations in the upper respiratory tract at concentrations of 50 to 150 mg/m^3 (25 to 75 ppm). Methoglobinemia and more severe symptoms such as somnolence, feelings of intoxication, syncope, and loss of consciousness occur after prolonged exposure. The gas can be detected by smell around 225 mcg/m^3 or 0.12 ppm, a lower concentration than that which produces neurological symptoms (Henkin, 1974, p. 200).

Mustafa et al (1977, p. 59) report that significant biochemical and morphological changes in the lung results from exposure to 5 ppm of nitrogen dioxide.

Nitrogen dioxide is considered to be more toxic than nitrous oxide. It is not very soluble in water, and passes through the trachea and bronchi into the alveoli of the lungs where it forms nitrous acid (HNO2) and nitric acid (HNO3). Both are irritating and corrosive to the mucous lining of the lungs. Rats subject to 2 ppm nitrogen dioxide for three days show damage to the cilia and various other lung changes. Even 0.5 ppm for a period of four hours produced distension of the alveoli of the lungs and a tendency to emphysema. Exposure of humans to 5 ppm (9.4 mcg/m^3) for 10 minutes produces a temporary increase in airway resistance. At 13 ppm, irritation of the respiratory mucous membranes takes place. (Waldbott, 1973, p.86)

Changes in sensory perception are the most sensitive indicators of the presence of nitrogen dioxide (NO2). Exposure of normal volunteers to the vapour of nitrogen dioxide produced changes in olfactory recognition thresholds, mainly increasing them, as well as a metallic taste in the mouth and pharyngeal roughness or dryness, at concentrations ranging from 0.1 to 30 ppm. Irritative symptoms lessened with repeated exposures and even disappeared at concentrations as high as 20 ppm. Increased humidity produced a sharp increase in odour perception and in irritation of the mucous membranes of the respiratory tract. Exposure to low concentrations of nitrogen dioxide, around 0.075 ppm, may also impair dark adaptation. The threshold for producing this sensory defect may be as much as 40% lower than that which produces changes in odour perception (Henkin, 1974, p. 200).

Yoshida et al (1974, p. 175) conclude that outdoor air pollution (including nitrogen oxides) can aggravate bronchial asthma by inducing hypersecretion from the secretory glands of the bronchial mucosa as well as bronchial spasticity. Their animal experiments are reported to show that NO2 causes histamine release in lung tissues and thereby facilitates sensitization with other antigens. They suggest that children with bronchial asthma in polluted areas should be quarantined from air-polluting substances in addition to undertaking hyposensitization therapy for specific antigens.

Melia et al (1977) (as reported in Hollowell and Traynor, 1978, p.9) reported that 2554 children living in English homes in which gas was used for cooking had significantly more respiratory illness than did 3204 children from homes in which electric stoves were used. In this study, the analysis of data collected took account of age, of individuals' social class, latitude of residence, population density, family size, crowding in the home, outdoor level of smoke and sulphur dioxide and the type of fuel used for heating the home. Smoking habits of parents were not considered in the analysis, but known relationships between smoking and social class were believed by the authors to allow for avoidance of at least some of the potential bias from this source.

The prevalence of bronchitis in homes using gas stoves was 5.7 and 4.7 percent for boys and girls respectively, compared to a prevalence in homes with electic stoves, of 3.1% and 2.0% for boys and girls respectively. Smaller but still statistically significant increases in "day or night cough", "morning cough", and "colds going to chest" were found for both boys and girls living in homes with gas stoves. Girls in these homes also had a significantly increased prevalence rate for "wheeze". The investigators concluded that elevated levels of oxides of nitrogen from gas stoves might have caused the increased respiratory illness.

In a later sample, Melia, Florey et al (1980) investigated the health of 808 schoolchildren in a small semi-urban area in northern England. No relation was found between kitchen levels of NO2 and the lung function or symptoms of the children or the symptoms of the other members of the family. However, respiratory illnesses were more frequent in children from homes with gas stoves, than from homes with electric stoves. The frequency of respiratory illness in the children in gas-stove homes increased with increasing levels of NO2 in the bedroom, after allowing for effects of age social class, smoking in the home, and family size. The researchers suggest that the bedroom levels of NO2 may be acting as a proxy for some other factor, such as lower temperature or increased humidity. Low temperatures have been found to be associated with respiratory illnesses in children.

In a study of households in six U.S. cities involving some 8000 children from the ages of 6 to 10 years, Speizer et al (1980, p. 7) found the following levels of significance (figures denote p-value, NS denotes 'no significance'):

	Low Social Class	Parents Smoke	Gas Stoves
History of doctor-diagnosed bronchitis	NS	NS	NS
Serious respiratory illness before age 2	.05	.01	.01
Respiratory illness in the last year	NS	.05	NS

Speizer et al (1980, p. 8) also found a significant correlation (p less than .01) between gas stoves and decreased lung function as measured by FEV$_1$ and FVC levels. (FEV$_1$ - Forced Expiratory Volume - was used as a measure of air flow obstruction, and FVC - Forced Vital Capacity - as a crude measure of lung size). There was at the same time a significant difference between lung function levels from city to city.

Discussion:

The behaviour of nitrogen oxides in the indoor environment, particularly the conversion from NO to NO2, is not well understood. NO2 has a relatively higher rate of decay than NO. (Young, G.S., 1981, p. 2-1)

Lawrence Berkeley Laboratory researchers have found nitrogen dioxide levels from indoor combustion sources often approaching or exceeding ambient air-quality standards either adopted or proposed in the United States and other countries (Hollowell, 1981, p. 5). In an earlier paper, Hollowell and Traynor (1978, p.4) also cautioned that in the gas stove studies done to that time, many nitrogen compounds, particulate as well as gaseous, had not been considered, despite the fact that it was known that the formation of hydrogen cyanide (HCN) and ammonia (NH3) had been observed in combustion processes. It had also been shown at that time that gaseous nitrogen compounds can rapidly undergo catalytic oxidation or reduction to other important air pollution species such as nitrates, nitric acid, ammonium, and organic nitrogen compounds of the amino and pyridino type.

Sterling et al (1981) reviewed available data on the emissions of gas ranges and concluded that the gas range is a "specifically critical appliance that may produce a number of harmful pollutants and may have a serious effect on the health of a very large number of individuals".

Shalamberidze (1967, 1970 as reported in Severs, 1980) reported on effects of NO2 and SO2 at outdoor ambient levels on the health of children. Mean diurnal concentration of NO2 ranged from 17 to 130 ppb. Physiological measurements on the children were made before and after the children's return to town from summer vacations at health resorts. Shalamberidze concluded:

> "Prolonged stay, for 9-10 months, in this polluted air evokes certain functional changes in children, indicating mobilization of the body's protective adaptive mechanisms to unfavorable external environmental influences. Continued exposure to this polluted air for several years not only caused functional changes, but also affected the health and physical development of children."

Goldstein (1971, as reported in Severs, 1980) concludes that the epidemiological data available supports the idea that respiratory impairment may occur in healthy populations and in patients with chronic obstructive respiratory disease following exposure to atmospheric levels of nitrogen dioxide.

1.2.4 **Sulphur Dioxide**

Description:

Sulphur is a natural constituent of coal and is used in various industrial processes. Sulphur dioxide is a colorless gas with an odor detectable at 0.5 to 0.8 ppm (1300-2000 mcg/m^3). It is more soluble in water than CO, NO, and NO2 and reacts with water, sunlight, and several particulate catalysts to form sulphur trioxide, sulphur tetroxide, sulphuric acid, and organic sulphates. Sulphur dioxide is very reactive and will attack and decompose powdered and alkali metals, fabrics, paper and marble. (Young, G.S., 1981, p. 2-3)

Major Sources:

Indoor concentrations of sulphur dioxide are related to the sulphur content of the fuel used for residential cooking and/or heating, and the infiltration of ambient pollutants from industrial operations and municipal power generation (Young, G.S., 1981, p. 2-3, and Hollowell, 1981, p. 4). Exposure from outdoor sources is highest in areas where sulphide ore is smelted, coal or fuel oils containing sulphur as an impurity are burned, paper is manufactured, or where petroleum is refined (Henkin, 1974, p. 196).

There is evidence, however, that where infiltration from outdoor pollution is involved, indoor SO2 levels can be significantly lower than those outdoors due to absorption by surfaces within a building (Crawshaw, 1978, p. 15). The most effective absorbing materials are cellulosic wallpaper, cotton and rayon furnishing fabrics, and wool carpets. The beneficial effect on indoor air concentrations is prolonged in the case of wool carpets, likely because of the high acid-combining potential of wool.

Concentration Range:

Indoor hourly concentrations of SO2 are typically below 20 ppb (50 mcg/m^3) (National Research Council U.S., 1981, p. II-6).

Sulphate concentrations indoors range from 2 to 15 mcg/m^3, and are typically at the lower end of the range rather than the higher. Usually levels are lower indoors than out. Fossil fuels are the most important source, including sulphur-containing compounds added to natural gas to provide detectable odour. (National Research Council U.S., 1981, p. II-6)

Standards:

Canadian Ambient Air Quality Standard for SO2 (from Statute Revision Commission, 1978a):

	desirable range		acceptable range	
	(mcg/m^3)	(ppm)	(mcg/m^3)	(ppm)
average over one hour	0 to 450	0 to .18	450 to 900	.18 to .35
average over 24 hours	0 to 150	0 to .06	150 to 300	.06 to .12
annual arithmetic mean	0 to 30	0 to .01	30 to 60	.01 to .02

United States (from Young, G.S., 1981, p. 2-14):

US - ambient air quality, annual arithmetic mean:	0.03 ppm	(80 mcg/m^3)
US - 24-hour ambient air quality standard SO2:	0.14 ppm	(360 mcg/m^3)
OSHA - PEL (Permissible Exposure Limit):	2 ppm	(5,100 mcg/m^3)
OSHA - Threshold Limit Value-Short Term Exposure Limit, (TLV-STEL) 15-minute short-term :	5 ppm	(12,800 mcg/m^3)

Incidence:

The 1981 U.S. National Research Council review (p. I-8) reports measurements of 20 mcg/m^3 (.008 ppm) SO2 indoors in one study of U.S. homes. The level was less than that outside presumably due to removal inside. Sulphates were 5 mcg/m^3, also less than the outdoor levels.

Young, in a study for the U.S. Gas Research Institute (1981, p. 2-14) cites measurements in U.S. homes yielding an average SO2 concentration of 0.015 ppm (40 mcg/m^3) over 24 hours (taken from Bierstaker, 1965). He also cites measurements by Yocom in one home, ranging from 0.007 ppm to 0.066 ppm (18-170 mcg/m^3), with a 24-hour average of 0.033 ppm (85 mcg/m^3).

Hollowell and Traynor (1978, p. 8) reported that the increase in sulphate in a typical kitchen is calculated and observed to be approximately 2 mcg/m^3 (.8 ppb) after operating a gas oven for 1 hour.

Health Effects:

Sulphur dioxide forms sulphurous acid rapidly on contact with moist mucous membranes, causing irritation of the upper respiratory tract. Acute exposure to concentrations above 20 ppm (50,000 mcg/m^3) additionally produces choking and sneezing. Mixtures of sulphur dioxide and aerosols often have a greater effect than might be expected from the two components acting independently, due to the transformation of sulphur dioxide into a variety of products, including sulphuric acid and sulphate salts, which are more highly irritating than sulphur dioxide itself. This synergism occurs with increased frequency in humid air, as sulphur dioxide dissolves in the vapour in the air and forms aerosols or soluble salts and acids. The tiny droplets carry the sulphur dioxide more deeply into the respiratory tract than would occur with sulphur dioxide alone. The droplets also provide an aqueous medium in which the chemical transformations to sulphuric acid and metallic sulphates may take place (Henkin, 1974, p. 197).

Petering (1977, p. 293) ackowledges sulphur dioxide's irritating and even lethal effects at high concentrations, but states that long-term exposure of animals to levels that more closely approximate conditions in the urban environment seem much less harmful. He does note, however, that bisulphite, a product of reaction between sulphur dioxide and water at the surface of the lung, is a moderately strong mutagen for certain bacteria in vitro, and that the presence of sulphur dioxide increases the incidence of cancer from benzo(a)pyrene in animals. (Benzo(a)pyrene is a carcinogen present in tobacco smoke). Rajagopalan and Johnson (1977) have concluded that present outdoor SO2 levels do not, however, present a genetic hazard because sulphite oxidase activity of the human lung is fully capable of detoxifying the amounts of bisulphite formed. Rather, the direct effect on the epithelial tissue of the lung is presumed to be the predominant hazard.

Persons at increased risk from outdoor pollution episodes involving sulphur dioxide are the young, the old, and those with cardiorespiratory diseases. Severs (1980, p. 123) reports that young males with bronchitis showed little change in pulmonary condition until a 24-hour average SO2 level of 0.3 ppm (770 mcg/m^3) was reached. At that level, however, there was a 100% increase in days of illness among a group of 561 bronchitics compared to days when levels were less than 0.04 ppm (100 mcg/m^3). Studies during air pollution episodes showed excess mortality from coronary artery disease, influenza, bronchitis and pneumonia coincident with elevated SO2 levels.

Barton (1981) reports that the average of annual mean outdoor sulphur dioxide concentrations for 69 Canadian cities was 12 ppb in 1979. Some 90% of the cities had levels below 18 ppb. The maximum desirable level under Canadian standards is 11 ppb.

1.2.5 Ozone

Description:

Ozone (O3) is a highly reactive gas consisting of three oxygen atoms. The ozone molecule decays rapidly by adsorption on indoor surfaces. (National Research Council U.S., 1981, II-5) The odour, sometimes referred to as an "electric odour", can be detected at concentrations from 0.2 to 0.05 ppm (400-100 mcg/m^3) (Waldbott, 1973, p. 88).

Major Sources:

Ozone usually arises indoors as a result of electric arcing (e.g. in electrostatic precipitators or from motor brushes), ultraviolet light sources, and intrusion from outdoor air pollution (National Research Council U.S., 1981, I-9, and Hollowell, 1981, p. 4). In outdoor pollution ozone commonly occurs as a result of the interaction of unsaturated hydrocarbons and nitrogen oxides in the presence of ultraviolet rays in sunlight, and is a constituent of smog in cities where motor vehicle traffic is heavy (Henkin, 1974, p. 199).

Concentration Range:

Typical indoor concentrations are 1-20 ppb (2-40 mcg/m^3), with peaks up to 120 ppb (230 mcg/m^3). Generally levels are lower than outside unless there is an indoor source such as an electrostatic dust precipitator (National Research Council U.S., 1981, II-5).

In U.S. urban areas, ozone concentrations were measured in the 0.001 to 0.3 ppm (2-600 mcg/m^3) range, with peaks of 0.9 ppm (1700 mcg/m^3) in Los Angeles smog. At times, ozone constitutes as much as 90% of the oxidants in smog. The 'first alert' level in Los Angeles is 0.05 ppm (100 mcg/m^3) (Waldbott, 1973, p. 88).

Indoor concentrations in the range of 20-200 ppb (40-400 mcg/m^3) are found in offices due to photocopiers (National Research Council U.S., 1981, I-9).

Standards:

Canadian Ambient Air Quality Standards (from Statute Revision Commission, 1978a):

	desirable range		acceptable range	
	(mcg/m^3)	(ppb)	(mcg/m^3)	(ppb)
average over one hour	0 to 100	0 to 50	100 to 160	50 to 80
average over 24 hours	0 to 30	0 to 15	30 to 50	15 to 25
annual arithmetic mean	—	—	0 to 30	0 to 15

Calabrese (1978b) cites the U.S. 1 hour maximum standard to be 160 mcg/m^3 (80 ppb). This level is not to be exceeded more than once per year.

Incidence:

Waldbott (1973, p. 89) notes that ozone can be produced in concentrations of 0.001 to 0.002 ppm (2-4 mcg/m^3) by properly functioning electrostatic air cleaners, and in concentrations of 1 ppm (2000 mcg/m^3) or more in defective units or those needing cleaning. The drier the air, the more ozone is being produced.

Health Effects:

Jaffe (1967) reviewed experiments of ozone exposures and concluded that within the range of 0.05 to 0.20 ppm (100-400 mcg/m^3) the following effects had been observed:

- irritation of the mucous membranes of the upper respiratory tract
- decrease in visual acuity and other changes in ocular parameters
- enhancement in mortality of respiratory infected test animals
- the sphering of red blood cells
- structural changes in the nuclei of myocardial tissue
- increase in mortality of newborn animals.

Hackney et al (1975) demonstrated a relatively broad range of sensitivity to ozone. Their experimental results support the idea that individuals with pre-existing pulmonary hyper-reactivity are more severely affected by exposure and thus more at risk in polluted environments. In limited trials, four subjects with a history of hyper-reactivity were significantly affected by 0.37 ppm (700 mcg/m^3) ozone, while four subjects without hyperreactive history were affected minimally or not at all at 0.5 ppm (1000 mcg/m^3). In the latter, addition of NO2 at 0.3 ppm (550 mcg/m^3) did not produce additional detectable effects. Addition of carbon monoxide at 30 ppm (34,000 mcg/m^3) also failed to produce detectable effects other than increases in blood carboxyhemoglobin levels.

Mustafa et al (1977, p. 89) note that significant biochemical and morphological changes in the rat lung result from exposure to 1 ppm (2000 mcg/m^3) of ozone. Their observations included depression of lung metabolism after high-level exposures (e.g. 2-4 ppm or 4000-8000 mcg/m^3 for 8 hours), elevation of metabolic activities after low-level exposures (e.g. 0.2 to 0.8 ppm or 400-1500 mcg/m^3 for 7-30 days) or during recovery from high-level exposures, and development of adaptation or tolerance against a continued low-leveled exposure. They note that augmentation of lung metabolism in low-level exposures or during recovery from a high-level exposure possibly represents a response of lung tissue to injury. The low-level exposures are comparable to those in mild to heavy smog in southern California. Exposure to higher concentrations of ozone might result in airplane cabins at altitudes above 30,000 feet, or in the vicinity of high-voltage electrical equipment during operation.

The biochemical changes noted by Mustafa et al (1977) were transient, and on a short-term basis there was an increased resistance against further lung injury in an oxidant environment. The authors stress that long-term effects are yet to be determined. Mudd and Freeman (1977, p. 97) report that scanning electron microscopy and transmission electron microscopy confirm damage to animal lungs in the region of the terminal and/or respiratory bronchioles, from ozone concentrations of 0.2 ppm (400 mcg/m^3) or more.

Yoshida et al (1974, p. 175) report that their animal experiments show that ozone can cause histamine release in lung tissues and thereby facilitates sensitization of the lungs with other antigens (see further discussion under nitrogen dioxide). Nadel and Lee (1977, p. 137) report that exposure of dogs to 0.7 to 1.2 ppm (1300-2300 mcg/m^3) ozone caused a marked increase of bronchial reactivity to inhaled histamine in otherwise healthy dogs. They suggest that airway epithelial damage is responsible for this increased reactivity, and may be particularly important in humans with pulmonary diseases.

Buckley et al (1977, p. 247) demonstrated significant changes in various blood parameters after exposure to 0.5 ppm (1000 mcg/m^3) ozone for 2.5 hours. Comparison of Los Angeles and Canadian volunteers indicated that residents regularly exposed to appreciable ozone levels showed less biochemical change upon ozone challenge.

Lagerwerff (1963, as summarized in Johnson, 1974) reported that visual function (visual acuity, peripheral vision, night vision, convergence and visual fields) was diminished by an ozone exposure of .2 ppm (400 mcg/m^3) for 3 hours. In experiments with dogs, Johnson (1974) demonstrated that 1 ppm (2000 mcg/m^3) of ozone administered for 16 hours per day over a period of 9 months caused abnormal EEG activity in the form of a mild depression of cortical function and slowing of the EEG.

Calabrese et al (1982) recently presented new data on the systemic effects of ambient ozone exposures in animals. Chromosomal aberrations have been detected in animals after 2-hour exposures at a level of .2 ppm (400 mcg/m^3), which is lower than peak Los Angeles outdoor ozone levels. Alterations in the red blood cell chemistry have been shown in rabbits under exposures from 0.06 to 0.48 ppm (115-900 mcg/m^3) exposure for 2.75 hours. Ozone in such concentrations has also shown unequivocal effects on drug action in animal models, suggesting the possibility of altered action of drugs in humans during indoor chemical exposures.

Evans et al (1976) discuss the phenomenon of tolerance to ozone after initial exposure, and cite experimental evidence using rats to show that tolerance to a continuous exposure of 0.35 ppm (700 mcg/m^3) ozone within four days, through renewal of lung tissue with different cell types. These changes did not, however, ensure total protection against a subsequent re-exposure at a level of 0.5 ppm (1000 mcg/m^3).

Calabrese (1980) reports that both ozone and nitrogen dioxide degrade Vitamin A via oxidation. (p. 70) He also cites other works suggesting that adequate levels of Vitamin A are necessary to repair tissue that is damaged by ozone, nitrogen dioxide and sulphur dioxide exposure.

It should also be noted that Vitamin E can mitigate health problems associated with exposure to ozone. (Health & Welfare Canada, 1983, private communication).

Discussion:

In this author's experience, reactions can be induced in some chemically susceptible persons upon exposure to the level of ozone produced by electrostatic precipitators and by some negative ion generators. However, some physicians have also reported improvement as a result of use of the same equipment, in other patients with similar sensitivities (Dickey, 1980, personal communication). Another patient reported improvement during high-level airplane flights, where ozone levels can be high. No mechanism has been postulated to explain the individual variations.

1.2.6 Asbestos

Description:

Asbestos is the generic name for several varieties of fibrous mineral silicates that occur in nature. The main varieties are chrysolite asbestos (white), crocidolite (blue), and amosite (brown). Asbestos fiber is resistant to heat, friction, and acid, and possesses high tensile strength as well as flexibility. (Waldbott, 1973, p. 198)

Major Sources:

Home exposure to asbestos is usually due to aging, cracking, or physical disruption of insulated pipes or asbestos-containing ceiling tiles and spackling compounds. Homes built before 1950 are more likely to have pipes insulated with asbestos plaster (National Research Council U.S., 1981, p. ES-6). Some other household products (e.g. old appliance wires) may contain asbestos which is disbursed in the air when such product becomes frayed or damaged. Apartment and school buildings may have an asbestos compound sprayed on structural components as a fire retardant.

Prior to 1980 in the United states, asbestos paper was sold to consumers, which released asbestos fibers at levels as much as 240 times the NIOSH recommended average level for occupational exposure over an eight-hour workday. Asbestos paper and asbestos paper tape were being used to insulate hot water pipes and heat ducts, and for wall protection near appliances such as stoves and ovens. Asbestos paper was being used for shelf lining, kitchen counter protection, dining placemats, automotive muffler repairs, and other home maintenance and repair uses. (California Department of Consumer Affairs, 1982).

In 1979 hand-held hair-dryers containing asbestos insulation were withdrawn from the North American market following the disclosure that asbestos fibers were blown out of the appliance into the surrounding air during operation. At that time the Consumer Product Safety Commission (U.S.) estimated that some 12.5 million hair dryers manufactured with asbestos insulation were in use by consumers.

Selikoff (1981, p. 956) notes that there are numerous sources of asbestos exposure in the home in the United States. For example, spackle compounds for taping joints on wallboard have over the years contained up to 12-15% asbestos. Some paper mache used in New York school systems contained up to 50% asbestos. There have been asbestos textiles, asbestos gloves, do-it-yourself brake repair work, and asbestos cement board for homeowner use. He notes that many homeowners may have done repair work on furnaces and pipes insulated with asbestos compounds. Selikoff also identified the use of 7% asbestos in coat fabric, apparently introduced by the manufacturer in order to reclassify the garment at a lower rate of import duty. The air sampled near the coat had asbestos levels higher than in some factories, and when washed, the garment contaminated other clothes with asbestos fibres.

In Canada, the use of asbestos in patching plaster has been banned under the Hazardous Products Act.

Concentration Range:

Typically indoor concentrations are usually less than 1 fiber/cc., which is about par with outside exposures (National Research Council U.S., 1981, p. ES-7). Studies of airborne asbestos concentrations in non-residential situations have yielded results ranging from 0.02 fibers/cc. (falling from exposed asbestos ceiling) to 17.7 fibers/cc. (during ceiling repair in a University building) (California Department of Consumer Affairs, 1982).

Standards:

United States (from Calabrese, 1978b, and California Department of Consumer Affairs, 1982):

US OSHA 1976 time-weighted average, 8 hr./day:	2 fibers/cc
US OSHA proposed change, 1975 for above:	0.5 fibers/cc
NIOSH 1977 time-weighted average, 8 hr./day	0.1 fibers/cc

Incidence:

The California Department of Consumer Affairs (1982, p. II.A.25) cites research which indicates that airborne concentrations of 5 asbestos fibers/ml. air (longer than 5 micrometers) were common during the use of drywall taping compounds containing asbestos. Also during the mixing of drywall taping compounds, fiber counts measured were found to be from 7 to 12 times greater than the current occupational standard. Detectable concentrations were reportedly found in the air in adjacent rooms as much as 15 minutes after mixing had ceased.

Health Effects:

Mesothelioma, a specific form of cancer (of the lung), is believed to result only from the inhalation of asbestos fibres (National Research Council U.S., 1981, p. ES-6). It appears to be unique among airborne inorganic microparticles, as Selikoff (1972, p. 62) has pointed out that there is no convincing evidence as yet of a cancer risk from inorganic dust other than asbestos.

Prior to the development of mesothelioma, persons exposed to asbestos may develop asbestosis, though in both cases the onset may be delayed 20 to 30 years after the exposure. Unexplained breathlessness and productive cough may precede the disease by many years, accompanied by tightness in the chest and pain. In the advanced stage, patients show cyanosis (bluish discoloration of the skin), restricted chest expansion, and the barrel type of chest seen in emphysema (Waldbott, 1973, p. 198).

Bronchogenic carcinomas, lung cancer, and cancer of the gastro-intestinal tract may also result from asbestos exposure (Health & Welfare Canada, 1983, private communication).

Discussion:

Reports of removal methods for commercial and institutional buildings have described both scraping and sealing as possibilities. This author has some reservation about the safety of widespread use of latex or other spray compounds to cover and permanently seal exposed asbestos. This kind of synthetic sealant can present significant immediate problems for persons who are generally susceptible to low levels of chemical exposure. There is no evidence yet that this problem has been taken into account.

One method of increasing safety during the removal of asbestos is that of thoroughly wetting the material before removing it. Individuals disposing of old asbestos items (e.g. paper, gloves, heater floor pads, etc., would be well advised to spray the item with water before attempting to remove it from the home (Russell, 1982).

Presently millions of dollars have been spent or budgeted in Canada for the removal of asbestos from public buildings. Asbestos is therefore a good example (in addition to Urea-Formaldehyde Foam Insulation) which demonstrates that mistakes affecting the indoor environment can be exceedingly costly to correct.

1.2.7. Tobacco Smoke

Description:

Tobacco smoke contains respirable particles as well as gases such as formaldehyde, acrolein, benzo(a)pyrene, and various trace metals (National Research Council U.S., 1981, p. ES-7). Respirable particles in tobacco smoke range from 0.01 to 0.5 microns in diameter (Young, G.S., 1981, Page 2-3).

Stedman (1968) reported that mainstream tobacco smoke contains 8% by weight of particulate matter with about 1200 different compounds identified, including: alkanes, alkenes, alkynes, ketones, aldehydes, alcohols, acids, esters, ethers, phenols, alkaloids, steroids, polynuclear aromatic hydrocarbons (PAH), various heterocyclic compounds (containing oxygen, nitrogen, and sulphur), and various metals. Almost 1000 different polynuclear aromatic hydrocarbons have been identified in cigarette smoke condensate (as reported in Brookman & Birenzvige, 1980, p. 9).

Waldbott (1973, p. 252) reported that among other chemicals, cigarettes contain about 30 mcg (micrograms) of cadmium per pack, 70% of which passes into the smoke. Lead content was measured to be about 60 mcg per pack and fluoride about 48 mcg per pack. He notes that the average smoker absorbs 10 mg. more lead per day than a nonsmoker. Hydrogen cyanide concentrations in cigarette smoke were measured to be almost 1600 ppm, whereas long term exposure to 10 ppm is considered dangerous.

The National Research Council (U.S.) Committee on Indoor Pollutants (1981, p. IV-101) lists the principal ingredients of mainstream and sidestream tobacco smoke as follows:

particles:

tar
nicotine
benzo(a)pyrene
pyrene
fluoranthene
benzo(a)fluorene
benzo(b/c)fluorene
chrysene, benz(a)anthracene
benzo(b/k/j)fluoranthrene
benzo(e)pyrene
perylene
dibenz(a,j)anthracene
dibenz(a,h)anthracene, ideno-(2,3-ed)pyrene
benzo(ghi)perylene
anthanthrene
phenols
cadmium

gases and vapours:

water
carbon monoxide
ammonia
carbon dioxide
nitrogen oxides
hydrogen cyanide
acrolein
formaldehyde
toluene
acetone
polonium-210

Major Sources:

Cigarettes, pipes, cigars.

This report is concerned not with the direct effects of inhaled fresh tobacco smoke on smokers but with the indirect effects on people of inhalation of "sidestream" smoke and mainstream smoke that has been exhaled by smokers. ('Mainstream' smoke is that which passes through the cigarette and into the mouth and lungs of the smoker. 'Sidestream' smoke is that which is produced by the lighted end of the cigarette directly into the room.

Hattori and Ro (1975) reported an emission rate of 5 mg. of carbon monoxide per minute from a burning cigarette. The amount of CO emitted in exhaled smoke ranges from 12% to 45% of the rate of burning alone. As much as 4.6 time as much CO originates from the sidestream smoke as from the mainstream smoke (Brookman & Birenzvige, 1980). The carbon monoxide emitted in sidestream smoke is fairly constant (at 50 +/-11 mg. per cigarette), but mainstream carbon monoxide can vary greatly with different cigarette brands and types (Health & Welfare Canada, 1983, private communication).

Girman et al (1982, p. 16) reports an emission rate of 130 mcg of carbon monoxide per milligram of tobacco burned. The particulate emission rate was 18 mcg/mg. Each cigarette contained approximately 600 mg. of tobacco.

Various researchers report that the number of particles per cubic centimetre emitted in cigarette smoke ranges from 1 to 6 billion, and that their average diameters are in the range 0.1-0.5 microns, which is respirable (Brookman & Birenzvige, 1980).

Incidence:

Health and Welfare Canada (Wigle, 1982) report that 37% of adult Canadians still smoke regularly (a total of seven million smokers), and that per capita consumption of cigarettes has been increasing in Canada despite evidence of the harmful effects of smoking. Approximately 35% of the U.S. population smoke (National Research Council U.S., 1981, p. ES-7).

Bridge & Corn (1972) reported that in a party in a 100 m^3 room with a ventilation rate of 10.5 air changes per hour, the average carbon monoxide concentration in the room over a 1.5 hour timespan was 9 ppm (10,000 mcg/m^3). There were 63 cigarettes and 10 cigars smoked during the party (as reported in Brookman & Birenzvige, 1980, p. 5).

Hinds (1978) reported on measurements in indoor public places, in which the concentration of nicotine in the air varied from 1 mcg/m^3 in a bus waiting room, to 10.3 mcg/m^3, in a cocktail lounge. He estimated that the contribution of tobacco smoke to the concentration of particulate matter varied in these places from 40 mcg/m^3 to 400 mcg/m^3 (as reported in Brookmam and Birenzvige, 1980. p. 13).

Brookman & Birenzvige (1980, p. 35) reported benzo(a)pyrene (BaP) levels in a restaurant ranging from 0.3 to 0.14 mcg/m^3. Benzo(a)pyrene levels of .002 to .004 mcg/m^3 were measured in a medium size room (40 m^3) from the

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sidestream smoke of three cigarette smokers (National Academy of Sciences 1972, p. 29, as reported in Shy, C. M., 1974). This is the same order of magnitude as outdoor ambient BaP concentrations of .0025 mcg/m^3 for U.S. urban locations surveyed in 1967, but greater than rural ambient concentrations in the same survey, of .0002 mcg/m^3 (National Academy of Science, 1972, pp. 49, 209 as reported in Shy, C. M., 1974).

Health Effects:

Primary effects are coughing, headache, nausea, and irritation of the eyes, nose and throat. Tobacco smoke has been well-documented as hazardous to health. Increased incidence of respiratory tract symptoms and functional decrements has been shown in children residing in homes with smokers, compared to those in homes without smokers (National Research Council U.S., 1981, p. ES-7).

A number of the polynuclear aromatic hydrocarbons in tobacco smoke have been identified as active tumorogens, with the most active among them being benzo(a)pyrene (Brookman & Birenzvige, 1980, p. 9). Tobacco smoking also interacts with asbestos exposure, increasing the cancer risk (Health & Welfare Canada, 1983, private communication).

Acrolein vapours are extremely irritating to the eyes and upper respiratory tract and can stimilate lacrimation (tearing) at concentrations as low as 625 mcg/m^3 (0.25 ppm) for as short a period as five minutes. The odour threshold has been reported to be at 525 mcg/m^3. There has been one fatal case of acrolein inhalation at 150 ppm (Henkin, 1974, p. 195). Ulsamer et al (1980) report that acrolein is one of the strongest cytotoxic and ciliotoxic agents known.

Repace (1982 and 1981) cites evidence which indicates that there are adverse health effects connected with passive smoking (non-smokers inhaling smoke produced by smokers). He notes that concentrations of tobacco smoke indoors are directly proportional to the smoker density and inversely proportional to the effective ventilation rate. He concludes that attempts to control smoking by ventilation are futile, because tobacco smoking "simply produces too much air pollution". The ventilation rates required are far in excess of those that can be accomplished economically (up to 30 air changes per hour), and would directly violate the goal of increased energy conservation.

In his 1981 paper, Repace quotes evidence from Bonham and Wilson (1981) indicating that over 60% of the children under 16 years of age in the United States may be living in homes with one or more smokers. The following chart gives the increase in the number of restricted activity days and bed-disability days due to acute respiratory conditions among children in smoking homes, compared with those in non-smoking homes:

	no smokers in the home	one smoker in the home	two or more smokers in home	45 or more cigarettes/day
restricted activity days	-	+7%	+29%	+46%
bed-disability days	-	+14%	+29%	+43%

Bonham and Wilson (1981) conclude that their data support the findings of others that cigarette smoking by adults adversely affects the health of children in their families.

Savel (1970) confirmed by an in vitro lymphocyte transformation method that there are people who are clinically hypersensitive to tobacco smoke in a manner similar to hypersensitivity to other agents such as tuberculin, drugs, viruses and pollens. Exposure of peripheral blood lymphocytes of eight individuals to tobacco smoke led to a stimulation of lymphocyte transformation. The hypersensitive subjects tested all had strong allergic histories such as drug reactions or hayfever, and all had moderate to intense upper respiratory discomfort after even a brief exposure to cigarette smoke. Symptoms typically appeared within 30 minutes to one hour after exposure to cigarette smoke and persisted for at least 8 to 12 hours. Half of the patients developed headaches the day following exposure, and in half of these the headaches were of migraine type.

The author also notes that several other individuals with the same symptom patterns did not demonstrate the same in vitro lymphocyte response. In a series of control patients, tobacco smoke exposure in vitro produced a depression of lymphocyte activity. Savel cites a previous report in which it was estimated that 10% of non-smoking allergic patients developed respiratory distress after being exposed to cigarette smoke (Pipes, 1945, as reported in Savel, 1970).

Aronow (1978) concluded that passive smoking can aggravate angina pectoris, after he conducted experiments on exercise-induced angina with non-smokers suffering from angina pectoris. The duration of exercise until the onset of angina was decreased 22% after inhalation of smoke passively in a well-ventilated room, and was decreased 38% after passive smoking in an unventilated room.

Wigle (1982) reports on data released by the U.S. Surgeon General which indicates that sidestream smoke contains many pollutants in considerably greater concentration than in mainstream smoke. In particular he cites high concentrations of two chemicals known to be human carcinogens: 2-naphthylamine and 4-aminobiphenyl. The American Conference of Governmental Industrial Hygienists (1981) indicates that for these and other carcinogens, "no exposure or contact by any route - respiratory, skin or oral, as detected by the most sensitive methods - shall be permitted".

It is interesting to note that in addition to affecting both smokers and bystanders directly, the inhalation of tobacco smoke may render people more susceptible to the effects of other pollutants. Calabrese (1978, p. 146) quotes a study by Carnow (1970) which found a higher rate of acute respiratory illness (e.g. cough and shortness of breath) in smokers as compared with nonsmokers at increasing levels of SO2. Carnow concluded that smokers constitute a higher risk group than even the elderly and the very elderly without cough and phlegm who were nonsmokers or mild smokers living in a large polluted city.

Lundqvist (1979, p. 276) showed that in rooms with smokers, odour intensity increased before irritation, and nose and throat irritation was occurring before eye irritation. After eye irritation started, it was given the highest score of irritation degree by an evaluating panel.

White and Froeb (1980) evaluated the effect of long-term passive smoking (involuntary inhalation of tobacco smoke by nonsmokers) on pulmonary function, and concluded that chronic exposure to tobacco smoke in the work environment is deleterious to the nonsmoker and significantly reduces small airways function.

Strasser (1979) suggests that the most efficient and simple way to reduce air pollution in industry is to ban smoking. He admits that his view is considered radical, but his argument is that great attention to reduction of other carcinogens in the workplace without attention to the problems caused by smoking is not entirely logical.

Calabrese (1978, p. 193) identifies tobacco smokers as a high risk group, indicating possible increased susceptibility to the effects of cadmium, hydrocarbons, lead, nickel, and radioactive compounds. In Canada in 1979, 48.8% of men 25 and over, and 32.5% of women 25 and over were smokers (Wigle, 1982). This risk group (now around 7 million people) represents approximately 30% of the Canadian population.

Tager et al (1979) cite various studies that demonstrate that children exposed to parents who smoke carry an increased burden of respiratory illness, observed as early as the first year of life and extending into the teens. Both acute respiratory illness episodes and chronic respiratory symptoms have been reported. Tager and co-workers investigated the effects of parental smoking patterns on lung function in 444 children in Massachusetts, USA, and determined that a child's passive exposure to cigarette smoke does have an adverse effect on the child's pulmonary function.

Discussion:

Girman et al (1982) measured emission rates of sidestream tobacco smoke in a special environmental chamber and concluded that sidestream cigarette smoke can pose a health risk in spaces where ventilation is reduced.

Lundqvist (1979, p. 276) conducted tests to determine the air exchange rates required to properly ventilate cigarette smoke. He measured suspended particulate matter, carbon monoxide, and droplet nuclei, and found that each characteristic component in the cigarette smoke will follow its own elimination function, depending on adsorption to surfaces, agglomeration or other interaction processes in the aerosol. His experiments indicate that a ventilation rate of 60-80 m^3 of fresh air/cigarette smoked, depending on the volume and characteristics of the room, is necessary to eliminate the tobacco smoke from the room before its adsorption in the room. He noted that tobacco smoke will create a definite health problem when air change rates are below 0.7 per hour, even at the lowest smoking rate of 6 cigarettes/hr tested in the study. With 6 cigarettes/hr smoked in an experimental chamber, 4 air changes per hour were required to limit the steady state concentration of carbon monoxide to 5 ppm (5600 mcg/m^3).

Seba and Repace (1982) conducted experiments with a negative ion generator and determined that such a device increased the effective ventilation rate in a smoke-filled room dramatically, providing 13 to 18 times faster removal of particulate matter from the air than would otherwise occur with air change rates below one air change per hour. An ion generator accomplishes this by charging smoke particles, which subsequently attach themselves to the surfaces of a room (e.g. ceiling and wall).

Health and Welfare Canada (Wigle, 1982) concludes that non-smoking must be re-established as the 'social norm' for all public areas, particularly indoor areas, through legislation and through education.

1.2.8. **Formaldehyde and other Aldehydes**

Description:

Formaldehyde (HCHO) is an inexpensive, high-volume chemical used throughout the world in a variety of products, mainly in urea, phenolic melamine and acetal resins. The resins are present in insulation materials, particleboard, plywood, textiles, adhesives, etc. that are used in large quantities by the building trades (Hollowell, 1981, p. 5).

Formaldehyde has a pungent and characteristic odour that can be detected by most people at levels below 100 mcg/m^3 (.08 ppm) (Hollowell, 1981, p.5).

Major Sources:

The major sources in North American housing are Urea-formaldehyde foam insulation, particleboard and plywood. More minor sources include other insulations such as fiberglass, and fabrics, carpets and furnishings. The latter may also adsorb formaldehyde from the major sources. Additional but lesser sources include cigarette smoke and other combustion sources such as gas-fired stoves, indoor gas-fired water heaters, unvented gas-fired space heaters, and portable kerosene-fired space heaters (National Research Council U.S., 1981, p. ES-5, Hollowell, 1981, p. 4, Traynor et al, 1981, p. 3, and Hollowell and Miksch, 1981, p. 3).

Outdoor sources of formaldehyde and other aldehydes include processes of combustion of hydrocarbons and other organic materials, including: exhausts from motor vehicles, incineration of wastes, and combustion of fuels (Henkin, 1974, p. 194).

Other products in which free formaldehyde may be present include: leather products, rubber, printing products, various plastics, photographic supplies, paper, latex paint, germicides, fumigants, and dyes. (Ulsamer et al, 1980).

Concentration Range:

Average indoor measurements of formaldehyde range from 0.01 ppm up to 1.0 ppm (12-1200 mcg/m^3) in homes with high rate sources (e.g. UFFI, particleboard) (National Research Council U.S., 1981, p. II-1).

Standards:

The Canadian guideline for acceptability of indoor air quality in homes, with respect to formaldehyde concentration, is .1 ppm (120 mcg/m^3). This level was chosen by the Department of Health and Welfare (Somers, 1982, p. 8) from consideration that the current allowable Threshold Limit Value (TLV) in the workplace is 2 ppm (2400 mcg/m^3) formaldehyde for healthy adults during a 40-hour work-week. A safety factor of 20 was incorporated in order to allow for the fact that households can include infants, young children, the old and the ill, and because the home environment may be occupied for 24 hours a day.

In Canada, lowering of the ceiling value in the workplace from 2 ppm to 1 ppm is intended (Health & Welfare Canada, 1983, private communication).

Norway, Denmark, the Federal Republic of Germany, the Netherlands, and Australia have also recommended or adopted 0.1 ppm (120 mcg/m^3) as an indoor standard for formaldehyde. A standard of .2 ppm (240 mcg/m^3) has been proposed by Wisconsin and California (Matthews and Howell, 1981).

A number of other countries and various states in the United States are moving rapidly to establish standards for formaldehyde concentrations in indoor air. The range of these proposed standards is 120 to 600 mcg/m^3 (.1 to .5 ppm) (Hollowell, 1981, p. 5).

Incidence:

Hollowell and Miksch (1981, p. 11) reported measurements of formaldehyde and other aliphatic aldehydes in a new energy-efficient house in Mission Viejo, California:

Condition	Formaldehyde		
	mcg/m^3	ppm	error
unoccupied, without furniture	80	.07	+/- 9%
unoccupied, with furniture	223	.19	+/- 7%
occupied, day	261	.22	+/- 10%
occupied, night*	140	.12	+/- 31%
outdoor air	less than 20	lt .017	

*all measurements except the night measurement were done at 0.4 air change per hour. For night measurements windows were open part of the time, and the air change rate was significantly greater than 0.4 and variable.

The increases in formaldehyde concentrations were attributed to the introduction of furnishings, and once occupied, to occupant activities such as gas cooking. Ventilation at night decreased formaldehyde levels significantly.

Lin et al (1979, p. 4) report that total aliphatic aldehydes and formaldehyde were measured at several energy-efficient research houses at various U.S. locations. Measurements of total aldehydes at 0.2 air changes per hour ranged from 40 to 220 mcg/m^3, and both formaldehyde and total aldehydes exceeded a criteria level of 120 mcg/m^3 (approx 0.1 ppm) at least part of the time. Corresponding outdoor aldehyde concentrations were less than 20 mcg/m^3 (.016 ppm).

Measurement of formaldehyde levels in several new office trailers were reported by Lin et al (1979, p.4). Concentrations ranged from 137 to 251 mcg/m^3 (.11 to .21 ppm), compared to 10 mcg/m^3 (.008 ppm) or lower outdoors. In one of the trailers, the formaldehyde concentration decreased from a range of 190-212 mcg/m^3 (.16-.18 ppm) to a range of 99-126 mcg/m^3

(.08-.1 ppm) after ventilation was increased from 0.16 to 0.35 air changes per hour. Outgassing of particleboard and plywood using urea-formaldehyde resins were thought to be the cause of high indoor levels in these trailers.

The Ontario Ministry of Health (1982) measured formaldehyde concentrations in 4920 homes insulated with Urea-formaldehyde Foam Insulation. The results of this survey were as follows:

HCHO ppm	mcg/m^3	Number of Homes		Percentage of Total Homes
lt 0.05	lt 60	3215	within	65.35%
0.05 - 0.1	60 - 120	1302	Canadian guideline	26.46%
0.1 - 0.2	120 - 240	359	beyond	7.3%
0.2 - 0.5	240 - 600	39	Canadian guideline	0.79%
0.5 - 1.0	600 - 1200	3		0.06%
gt 1.0	gt 1200	2		0.04%
total		4920		100.0%

Traynor et al (1982, p. 3) measured formaldehyde levels due to operation of both convective and radiant-type portable kerosene heaters, in a 27 m^3 environmental chamber with 0.4 air changes per hour. Levels reached .013 ppm (16 mcg/m^3) for a new convective heater under full-wick conditions, and .066 ppm (80 mcg/m^3) for a new radiant heater under full-wick conditions. These levels were below U.S. occupational and outdoor air quality standards. Adjustment of the wick length to one-half on the convective heater increased the formaldehyde emission rate by a factor of 4. Only a slight increase in formaldehyde emission was detected when the radiant type was adjusted in a similar manner.

Health Effects:

Reported health effects of formaldehyde include skin, eye and throat irritation, respiratory disorders and allergies, and a decreased threshold of reactivity with prolonged exposure. High exposure levels have produced nasal cancer in rats (National Research Council U.S., 1981, p. ES-5).

In Canada, an Expert Advisory Committee to the Department of National Health and Welfare recommended that Urea-Formaldehyde Foam Insulation be banned, partly on the basis of the potential carcinogenicity of formaldehyde as revealed by the Chemical Industry Institute of Toxicology's study revealing nasal cancer in rats at 15 ppm (18,000 mcg/m^3) exposure. Somers (1982, pp 2,6) notes, however, that attention was also drawn to the possible allergenic reactions that could be caused by a host of fungi that have been identified in UFFI. The committee acknowledged that, at low concentrations, formaldehyde can elicit a range of non-specific symptoms such as eye, nose and throat irritation, coughing, headaches and dizziness. They noted that some individuals can be acutely sensitive to formaldehyde and can detect concentrations well below 1 ppm, and that increased sensitivity to formaldehyde is particularly serious to those with a history of respiratory allergy. Somers (1982, p. 8) also states that persons already afflicted with asthma might find their response to other allergens aggravated after exposure to formaldehyde.

Several studies reported in the literature indicate that concentrations in the range of 100 to 200 mcg/m^3 (.08-.17 ppm) may be sufficient to cause swelling of the mucous membranes, depending on individual sensitivity and environmental conditions (temperature, humidity, etc.) Burning of the eyes, weeping and irritation of the upper respiratory passages can also result from exposure to relatively low concentrations. High concentrations (above 1000 mcg/m^3 = .83 ppm) may produce coughing, constriction in the chest, and a sense of pressure in the head (Hollowell, 1981, p. 5). In some industrial situations irritant effects were not reported until concentrations reached 2-3 ppm (2400-3600 mcg/m^3) or even 4-5 ppm (4800-6000 mcg/m^3) (Henkin, 1974, p. 195).

The threshold for effects shown by electroencephalogram is 0.043 ppm 52 mcg/m^3). (National Research Council US, 1981, p. I-29) Henkin (1974, p. 194) states that the cortical reflex threshold has been observed to be about 98 mcg/m^3 (.08 ppm).

Rea et al (1981) demonstrated 50% depression of C3 complement levels in one patient exposed to a short (2 sniff) challenge to 0.2 ppm (240 mcg/m^3) of formaldehyde. Symptoms produced in a number of patients after similar formaldehyde challenges included hoarseness, nausea and vomiting, shortness of breath, loss of peripheral pulse, and spasm of gastrocnemius with severe tetany.

The principal effect of the other aldehydes is irritation of the eyes and skin (Henkin, 1974, p. 195). Olefins or unsaturated aldehydes and the halogenated aldehydes generally produce a more noticeable irritation than do saturated aldehydes. Aromatic and heterocyclic aldehydes generally cause less irritation than saturated aldehydes. Toxicity of aldehydes decreases with increasing molecular weight and generally decreases as chain length increases. Although aldehydes possess anesthetic properties, these effects are generally obscured by their irritant effects and by their rapid metabolism.

The Ontario Ministry of Health (1982) reported on health survey results from 1406 UFFI-insulated homes, a subset of the 4920 homes in which formaldehyde levels had been taken (see above). The total number of occupants in these homes was 4528, of which 2762 or 61% reported symptoms. In the study symptoms were recorded for persons complaining of a "health problem which had been persistent; which began or became worse since the insulation was installed: which may be aggravated while in the housing unit, and which has not been attributed to anything else" (Ministry of Health, Ontario, 1981, p.2).

The following table shows the number of persons with symptoms compared to measured formaldehyde levels, in the Ontario study:

HCHO in ppm	HCHO mcg/m^3	No. of Homes	No. of Occupants	No. of Occupants with Symptoms	% with symptoms (each category)	
lt 0.05	lt 60	887	2871	1719	59.87%	
0.05 - 0.1	60 - 120	373	1175	739	62.89%	Canadian
0.10 - 0.2	120 - 240	123	409	253	61.85%	guideline
0.2 - 0.5	240 - 600	21	65	47	72.3%	
0.5 - 1.0	600 - 1200	1	5	3	60.0%	
gt 1.0	gt 1200	1	3	1	33.3%	
total		1406	4528	2762	100.0%	

Of the 2762 persons studies who reported symptoms, 19.4% had previous allergies, and 5.4% reported previous asthma. Some 65% of those reporting symptoms included eye irritation, cough or sore throat. A second group of symptoms including sneezing, nasal congestion, bronchial congestion, colds, sinus congestion, and itchiness of the skin was reported by 41% of the sample. Other symptoms reported were headache (30%), fatigue (22%), shortness of breath (14%), dizziness (14%), rash (13%), nose bleeds (11%), diarrhea (4%) and vomiting (3%).

Morris (1982) reported a comparative survey of 60 families in each of two northern U.S. housing developments, one of which (Deer Creek, SD) had levels of indoor formaldehyde concentrations consistently higher than the other (Pebble Creek, SD) by a factor of five. In the housing development with the higher formaldehyde concentration there was twice the amount of eye irritation and more complaints of sore throats, colds, coughing, runny noses, sinus problems, loss of motor control, drowsiness, rashes, itching and dizziness. Approximately 21% of the group in the higher formaldehyde level homes felt they they had been sicker than normal after moving into their new home. Among the problems in the higher formaldehyde level homes were several cases of severe central nervous system disorders which were determined to be related to indoor chemical exposures, including formaldehyde.

Cases of widespread chemical susceptibility, triggered or exacerbated by exposure to formaldehyde and other gases in UFFI-insulated homes, have been reported (Small, 1982a). Typically the householder develops several symptoms, including eye and throat irritation, headache, and fatigue.
In the early stages these symptoms subside immediately on leaving the UFFI home. Later the same kinds of symptoms are triggered in other environments, as the sensitivity 'spreads' to other chemical exposures. One death was reported to this author, involving liver damage possibly related to acute formaldehyde exposure (15 ppm = 18,000 mcg/m^3) in a UFFI home (Palmero, 1982 and Small, 1982a). Early symptoms after the initial exposure had followed the pattern of widespread chemical susceptibility.

Sprague et al (1982) confirmed further cases of formaldehyde and other chemical susceptibility at low concentrations, following exposure to the inside of mobile homes, new plywood, particle board or wallboard. Sensitivities to various chemicals as follows were confirmed by means of double-blind challenge exposures:

formaldehyde	(at less than 0.2 ppm or 240 mcg/m^3)
phenol	(at less than .002 ppm)
chlorine	(at less than .33 ppm)
2,4DNP pesticide	(at less than .00134 ppm)
petroleum alcohol	(at less than 0.5 ppm)

Specific symptoms among a group of eight patients included cardiac arrythmia, laryngeal edema, severe facial angioedema (swelling), fatigue, dizziness, and vertigo. Depression of total T-cell populations was found in some patients but it was reported that this was not found in all the patients tested.

Discussion:

Sources such as particleboard and plywood have contributed significantly to indoor formaldehyde problems in mobile homes because of a high surface to room volume ratio of those materials, combined with tight construction and low ventilation rates (National Research Council U.S., 1981, p. ES-5).

Lawrence Berkeley Laboratory researchers have also found formaldehyde levels from combustion appliances often approaching or exceeding ambient air-quality standards either adopted or proposed in the United States and other countries (Hollowell, 1981, p. 5).

1.2.9 Carbon Dioxide

Description:

Carbon dioxide (CO_2) is a colourless gas, of molecular weight 44.01 compared with 32.0 for molecular oxygen, and is usually considered a simple asphyxiant. It is also a potent stimulus to respiration and both a depressant and excitant of the central nervous system. Because carbon dioxide is heavier than air, pockets of the gas may persist in areas such as pits for some time unless ventilation is provided. The U.S. Threshold Limit Value of 5000 ppm (9 g/m^3) was chosen to provide a good margin of safety from known asphyxiation and systemic effects. (Proctor and Hughes, 1978, p. 147). (g/m^3 = gram per cubic metre)

Major Sources:

Indoor sources include combustion and human and animal metabolism (National Research Council U.S., 1981, p. I-9). Flue gases are a major outdoor source (Henkin, 1974, p. 199).

Concentration Range:

Up to 3000 ppm (5 g/m^3) indoors, very much greater than outdoor concentration. Observed typical outdoor concentrations are approximately 400 ppm (.7 g/m^3) (National Research Council U.S., p. I-9, II-4).

Standards:

Canada: no standards for indoor air

United States (Traynor et al, 1982, p. 2 and Consumers Union, 1982):

EPA:	none		
OSHA:	8-hour occupational exposure:	5,000 ppm	(9 g/m^3)
ASHRAE:	non-workplace indoors:	2,500 ppm	(4.4 g/m^3)

Incidence:

Indoor concentrations were greater than outdoor concentrations for approximately 90% of monitored hours, and hourly indoor concentrations often exceeded 2000 ppm (3.5 g/m^3). (National Research Council U.S., 1981, p. II-4)

Traynor et al (1982, p. 2,8) measured CO_2 emissions from portable kerosene-fired heaters in a 27 m^3 environmental chamber with 0.4 air changes per hour ventilation. For both radiant and convective type heaters, CO_2 levels exceeded 10,000 ppm (18 g/m^3) after 60 minutes of heater operation. This is twice the U.S. occupational standard.

Health Effects:

The World Health Organization (1979) states that there is reason to be concerned about long-term consequences of changes in the acid-base balance in humans if indoor carbon dioxide exposures exceed 0.5% (5000 ppm or 9 g/m^3). They suggest that, because of decreasing ventilation rates for energy conservation, the data on effects of moderate concentrations (1000-5000 ppm or 2-9 g/m^3) should be re-examined.

Henkin (1974, p. 199) reports that at concentrations of 50,000 ppm or 5% carbon dioxide in air (90 g/m^3), dizziness, headache, and confusion occur. At 8-10% (140-180 g/m^3), severe headache, dimness of vision, and tremor, and even unconsciousness if this level is maintained for 5 to 10 minutes. Concentrations of 25-30% (450-500 g/m^3) have been associated with diminished respiration, hypotension, coma, areflexia, and anesthesia. At these high concentrations consciousness is lost almost immediately and death may ensue.

1.2.10 House Dust and Dust Mites

Description:

House dust consists of a variety of substances, including cotton, wool and other fabrics, dyes from materials, food particles, hairs, dead skin cells, dust mites, animal danders, decomposed material, bacteria, pollens and fungi (Waldbott, 1973, p. 186, and Lowenstein et al, 1979, p. 112).

House dust also contains various natural and synthetic fiber particles shed from furnishings and clothing within the home.

Major Sources:

Lowenstein et al (1979, p. 112) report that there is a great variation in the potential allergenic material in the dust found in different homes. One analysis revealed 45 different antigenic components, of which 18 could be ascribed to known allergenic sources like animal danders, feathers, mites, pollen, food leftovers and human dander.

Zamm (1980, p. 97) cautions that carpeting can entrap housedust and become a hazard for the sensitive individual, releasing a 'housedust smog' every time someone walks across it. It can also generate dust and vapours itself.

Concentration Range:

No data was found during the literature search.

Standards:

None.

Incidence:

Korsgaard (1979, p. 192) found a highly significant relation between water vapour content of indoor air and the concentration of mites in mattress dust. Low concentrations of mites (an average of 1 or fewer mites in a .1 g dust sample) were found in dry conditions (less than 7.0 g/kg water vapour in dry air). Above this level the concentrations were moderate (av. 15 mites per sample), and the greatest concentrations of mites (av. 100 mites per sample) were found when the water vapour exceeded 7.9 g/kg of dry air.

A small number of mites was also found in bedroom and living room carpet samples, but the differences under varied humidity conditions were not significant in the samples studied.

A water vapour content of 7.0 g/kg dry air at 20-22 degrees C corresponds to a relative humidity of about 45%. In the bed, water vapour emission from the human body causes a local increase in the relative humidity in the bed from 45 to 55% RH for about 8 of 24 hours. Mites require a humidity range of 55-80% to increase in numbers.

Health Effects:

House dust contains allergenic compounds which may initiate and provoke immunologically hypersensitive reactions in people. These reactions may also be caused by low molecular weight chemical compounds in dust and in air, such as formaldehyde, other aldehydes, epoxides, diones and acid anhydrides, when acting as haptens (combining with proteins). Depending on the size and shape of dust particles, they may penetrate the human airways, be dissolved and cause allergic reactions. The amount of house dust material which may give rise to hypersensitivity is highly dependent on the actual dust and on the individual person (Lowenstein et al, 1979, p. 114).

Mathews (1978) states that aggravation of allergic respiratory symptoms by exposure to various types of dust is extremely common. Depending on the nature of the dust, responses may be due to irritation or may be immunologically mediated. He notes that among the inhalant allergens other than pollen and fungi, house dust is of major importance, but identification of the allergenic substances in this heterogeneous substance is difficult.

Mansmann (1978) describes avoidance as a 'well-recognized, logical and necessary' form of therapy often instituted by an allergic person even before consulting a physician. He advises that for the dust-allergic person, bedding should be easily washed, and the bedroom should be uncluttered with dust-collectors. He also cautions that highly dust-allergic persons should stay out of the house during and for several hours after vacuuming. Mansmann also offers further advice on dust, mite, and fungus control for the allergic patient.

Muittari (1978, p. 50) concluded from a study of textile workers in Finland that natural and synthetic fibers act in a similar way to allergens such as pollens, animal danders, and moulds. His study suggests that natural fibers can act as allergens that stimulate the synthesis of IgE antibody, and that synthetic fibers may act as 'haptens' (linking with proteins to cause allergy) and as non-specific irritants of the respiratory tract, causing asthma and rhinitis. (IgE antibodies mediate reaginic hypersensitivity reactions in vivo and in vitro and participate in the induction of allergic manifestations (Ishizaka and Ishizaka, 1978).)

Discussion:

Avoidance of dust has often been prescribed for persons who are allergically sensitive to it. In general, careful cleaning and vacuuming, and air filtration are effective in reducing dust levels in a home. Most household vacuums also return small amounts of very fine dust particles to the air (out the blower end), which may aggravate dust sensitivities if those who are allergic are present during cleaning. For some the odours of the vacuum motor may also present a chemical problem sufficient to trigger symptoms. Central vacuum units with both the motor and the exhaust completely outside the house are a good alternative in such cases.

1.2.11 Fungi (Mould and Mildew)

Description:

A broad class of biological organisms, characterized chiefly by the absence of chlorophyll and by subsisting upon dead or living organic matter, including moulds, mildews, rusts and smuts. The most common of the fungi in indoor environments are the moulds, which are minute fungi that form on vegetable or animal matter, commonly as a downy or furry coating, and associated with decay. The word mildew is commonly used to describe any coating or discoloration on fabrics or building materials that is caused by any fungus in a moist environment. In this report the words mould or fungus shall be used interchangeably to refer to any spore-producing organism, or its spores, present in the indoor environment (Random House Dictionary, 1968 Edition, Random House, New York).

Major Sources:

Fungus spores occur naturally in outdoor environments and may also be produced by fungal colonies indoors. Moist environments (e.g. in air conditioning coolers and humidifiers) encourage growth. Spores, moulds and fungi multiply in the presence of increased humidity generally in the indoor environment (National Research Council U.S., 1981, p. ES-9). If the relative humidity rises above 70%, growth of moulds and bacteria, incidence of dust mites and survival of airborne pathogens will increase (World Health Organization, 1979).

Concentration Range:

Bravery (1980, p. 4) notes that there has been little published scientific work on the types of fungi occurring within mould-infected buildings or on the concentrations of spores encountered in the atmosphere of dwellings. He cites reports indicating that spore concentrations outdoors seldom exceed $10^5/m^3$ and rarely reach $10^6/m^3$, and concludes that concentrations in normal dwellings are likely to be somewhat lower.

Standards: none

Incidence:

Brundrett (1981) states that dampness encourages mould growth which eventually leads to deterioriation of building components such as wallpaper, plasterboard and timber. The mould develops from spores which are ever-present in outdoor air and quickly settle in all houses. Since nutrient is plentiful, once suitable conditions of moisture and temperature ocur, then mould will grow. Below certain relative humidities, usually 70%, the spores will not germinate. All houses contain a wide variety of species of mould spore which develop best over a range of temperatures. It is important to prevent mould from becoming established. Once mould starts to grow then one of the by-products of its metabolism is water. Established mould can therefore continue to grow even when the ambient conditions are too dry to germinate mould spores elsewhere.

One study cited by Bravery (1980) sampled several hundred dwellings for airborne spores and recorded more than 95 species of fungi. The species most commonly encountered were Penicillium, Cladosporium, Rhizopus nigricans, Mucor, Trichoderma viride, Botrytis cinerea, Alternaria tenuis, and Fusarium. Many species have been reported to colonize cellulosic materials and fabrics, but fewer have been shown to colonize paint, plaster and stone surfaces. Mould growth is likely where surfaces inside buildings become regularly or intermittently moist and relative humidities exceed 70 percent. The species of fungi involved are widespread in the natural environment and their spores are commonly present in the atmosphere. Control measures must concentrate on reducing and eliminating the sources of water and water vapour.

A recent Syracuse study (Rogers, 1982) found that the top 12 organisms recovered in domestic samples were as follows, in the order of prevalence:

Cladosporium (Hormodendrum)
various bacteria
Aspergillus
Penicillium
yeasts (not including Rhodotorula)
Basidiomycetes (a group of fungi that have to do with wood rot in the home)
Rhodotorula
Trichoderma
Epicoccum
Alternaria
Microsphaereopsis
Aureobasidium (Pullularia)

The researcher notes that in hundreds of home cultures, their laboratory has never seen a house without mould growth nor one without bacteria and yeast as well.

Lowenstein et al (1979, p. 112) reported that the seasonal variation of indoor airborne fungi corresponds to the outdoor flora. The dominating airborne moulds are Cladosporium, Penicillium, Alternaria, Rhodotorula and Aspergillus, while the dominating dustbound moulds are Mucor, Penicillium ad Alternaria. Fungi in the outdoor atmosphere do not follow as consistent a pattern as that of pollens, although some species such as Alternaria and certain yeasts and rusts do vary seasonally, with the major occurrence in the warmer months (Waldbott, 1973, p. 184).

Doris, Harper & Morris (1972, p. 1) note with respect to fungal growth in submarine environments that fungi are able to utilize any hydrocarbon for growth by producing new enzymes, and in this way can colonize oil smeared surfaces, precipitator condensates, and even the charcoal granules used for removing hydrocarbon contaminants from the atmosphere. (With respect to the latter, low measurements of fungal spore concentrations in nuclear submarine atmospheres would indicate that an activated charcoal recirculating system is a trap rather than a source of fungal contamination of indoor air.)

Brundrett (1979, p.1) states that any humidification device involving recycled and/or standing water subject to stagnation may be a potential source of contamination from micro-organisms including various fungi.

Health Effects:

Fungi produce two kinds of respiratory diseases. In the first, they act as antigens similar to pollens, and precipitate allergic reactions both in the respiratory tract and on the skin. They can more rarely produce pulmonary infections (e.g. aspergillus, monilia) similar to those caused by bacteria and viruses, characterized by fever and gradually increasing shortness of breath (Waldbott, 1973, p. 186). Others (Rogers, 1982) emphasize that mould allergy can effect many different organs of the body.

Kozak et al (1980) emphasize as well that allergenicity of mould spores can be shown to be independent of their viability, and therefore in some cases killing the mould spores with a variety of chemicals is of limited value. As a result they recommend physical removal of the spores and correction of the physical conditions that led to their growth. They also note that while most cases of mould allergy appear to be related to the mould spores themselves, it is also possible to become sensitive to the mycelial fragments, which are also present in indoor air.

See also "Humidifier fever", described in Section 1.2.12 "Bacteria & Viruses" following.

Discussion:

The amount and type of pigment and resin in a paint can affect the degree to which a wall surface will support mould growth. Generally, oil paints produce water-resistant, coherent films which tend to reduce the mould susceptibility of a surface. Certain resin-based paints, e.g. an alkyd resin made from a vegetable source, can contribute to mould growth, but as the degree of polymerization increases, the susceptibility of the resin to mould decreases. Often fungicides are added to paint to inhibit mould growth (Bravery, 1980).

1.2.12 **Bacteria and Viruses**

Description:

Various infectious organisms including viruses and bacteria are airborne in indoor air and do circulate from room to room. These airborne infectious agents are capable of causing disease when they come in contact with a susceptible host (Michaelson, 1979, p. 229).

Major Sources:

Human activity and presence of domestic animals (National Research Council U.S., 1981, p. ES-9). Riley (1981) notes that many infectious organisms are atomized by coughing, sneezing, singing and even talking. The smallest droplets evaporate to droplet nuclei and are dispersed rapidly throughout the air in an enclosed space.

Brundrett (1979, p.1) states that any humidification device involving recycled and/or standing water subject to stagnation may be a potential source of bacteria and other micro-organisms such as amoebae and fungi.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1981) also warns that heating, refrigerating, ventilating and air conditioning systems, can be involved in the distribution of a variety of airborne contaminants.

Concentration Range:

(no data found in literature search)

Standards:

(none for indoor air)

Incidence:

Couch (1981, p. 910) sampled the contribution of coughing, sneezing and other expiratory events to room air contamination by virus-infected volunteers, after a period of two hours in a room with no ventilation. Fourteen of thirty samples contained virus, and the frequency of positive samples increased with increasing quantities of virus in respiratory secretions. It was found that the presence of virus in cough air samples from volunteers occupying a room was significantly related to the recovery of virus from the air of that same room on the same day. No such relationship was detected for sneezing, possibly because sneezing occurred infrequently, whereas coughing was frequent. Couch concluded that cough was a major event for producing air contamination.

ASHRAE (1981) notes that air handling and conditioning equipment is suspected of being involved in the dissemination of the Legionella species of bacterium which has caused illness and death in several outbreaks since 1976 in the United States. Another possible source of Legionella bacteria is soil excavation. Water or wet soil appears to be the habitat for the organism, and it has been isolated in soil, water, mud, and especially in thermally polluted waters. Concentrations of 10^6 stainable organisms per liter have been found in thermally polluted ponds. The bacterium appears to be part of the natural aquatic community and may, on occasion, comprise as much as 10 percent of the total bacteria population of a lake.

Legionella has also been isolated from shower heads and shower water, from hot water tanks and humidifiers fed by potable water supplies, and from domestic water taps, sewage treatment facilities, and recreational waters in the United States. It is not known whether contamination of shower heads and taps by Legionalla originates from contamination of source water entering the distribution systems, or from external contamination at the tap.

Health Effects:

Bacteria and viruses can produce infection, disease, and allergic reactions. Respiratory viruses can be transmitted from person to person (National Research Council U.S., 1981, p. ES-9).

"Humidifier fever" described by Brundrett (1979, p.3) produces symptoms similar to those of influenza. Fever and malaise are the main symptoms, but cough, chest tightness, difficulty in breathing and loss of weight may occur. Aches in the joints and shivering are also reported. The symptoms normally appear a few hours after the start of the exposure, and are most severe on re-exposure after an absence from the contaminated room. If the contamination occurs at work it will be at its worst on Monday afternoon and evening, giving rise to 'Monday sickness'. The symptoms diminish in severity as the week progresses.

Assendelft et al (1979, p. 35) also report cases of allergic alveolitis related to micro-organisms growing in home humidifiers. The alveolitis developed over varying periods from 4 weeks to 3 years. Lung function usually returns to normal in some days to a few weeks in acute cases, and in some months to two years in chronic cases. They note that bacteria and other organisms from humidifiers have caused bacterial infections, worsening of bronchial asthma and, in some hospital cases, fatal Pseudomonas pneumonia.

Initial symptoms of legionellosis of the type that occurred in a 1976 outbreak at a Philadelphia convention (Legionella pneumophila) include fever, chills, headache and muscular aches and pains, often followed by pneumonia (ASHRAE, 1981). The disease may be accompanied by cough, chest pain, shortness of breath, mental confusion, vomiting and diarrhea lasting for 10-15 days. In addition, signs of injury to liver and kidneys are sometimes observed. About 15 percent of the known cases have been fatal. This particular infection does not appear to spread from person to person. Case rates have been higher among people who smoke, drink, have chronic illness or are under medical treatment regimes which are immunosuppressive, i.e., depress the body's defense mechanisms against bacteria.

Discussion:

Substantial reductions in ventilation rates will tend to increase concentrations and most likely the probability of infection and allergy (to the extent that infectious and allergenic microorganisms remaine airborne) (National Research Council U.S., 1981, p. ES-9).

ASHRAE (1981) noted that certain systems provide conditions to amplify natural populations of the Legionella bacteria, including (but not limited to): cooling towers, evaporative condensers, humidifiers, hot water systems, including tanks, shower heads, and faucet aerators. Pan and spray-type humidifiers downstream from a domestic heating source are also cited as possible amplifiers. The doubling time of Legionella, in association with some of these 'amplifiers', has been reported to be as short as 150 minutes at 45 degrees Celsius under laboratory conditions. In all of the amplifiers reported to date, two environmental conditions have existed:

1) high moisture levels
2) temperature in the range of 25-63 degrees Celsius

The presence of a blue-green algae may also play a role. The maximum concentration of Legionella in such amplifiers seems to occur in water at about 55 degrees Celsius.

Jakab and Knight (1981) emphasize that microorganisms in the indoor environment have the potential of remaining viable and airborne for extended periods of time. Their experiments with germicidal irradiation of air show that exposure of the air flow to ultraviolet radiation was effective in significantly inactivating airborne viruses.

Bacteria and fungi also play an important role in the deterioration of surfaces and spoilage of stored materials (National Research Council U.S., 1981, p. II-6).

1.2.13 Consumer Product Aerosols

Description:

Marple and Rubow (1980, p.3) define an aerosol as a suspension of particles in air, although other gases may be present. The particles may be either liquid or solid. In many homes various aerosol products are used which introduce both propellant gases and the aerosol ingredients into the indoor environment.

Friedman et al (1978, p. 284) states that typical ingredients of hair spray formulations include Freon (propellant), ethyl alcohol, perfumes, lanolin and its derivatives, and various resinous materials. The particle size and distribution depend on the formulation of the product, the details of the nozzle release mechanism, and on the temperature of the container and its contents. Measurements cited by these researchers indicate that inhaled hair spray aerosol consisted of particles with a mass median diameter of 7.8 micrometers. Many particles would be expected to be deposited in the lower airways, including the trachea where Friedman's measurements were made.

Major Sources:

Examples of consumer products aerosols containing propellants include: inhalants containing bronchodilator drugs, mouth products, vaporizers, hair products, women's personal hygiene products, deodorants and anti-perspirants, foot products, household cleaning and waxing products, cooking oil, etc. (Bridbord et al, 1975). Pesticides, lubricants and various workshop items are also sold in aerosol form.

Concentration Range:

Bridbord et al (1975) report propellant concentrations up to several 100 ppm during and immediately after spraying, in the zone of the spray.

Standards:

None uncovered in literature search.

Incidence:

Specific measurements reported in a U.S. study by Bridbord et al (1975) showed a concentration of 122.7 ppm vinyl chloride and 62.1 ppm Freon 12 in the breathing zone during a 60-second release of hairspray. The concentrations of vinyl chloride and Freon 12 one minute after a 30-second release of insect spray were 380 ppm and 466 ppm respectively. In Canada, vinyl chloride, which is known to be carcinogenic to humans, has been banned in aerosols under the Hazardous Products Act (Health & Welfare Canada, 1983, private communication).

Health Effects:

Friedman et al (1977, p. 281) observed healthy nonsmoking subjects exposed to hair spray by directing the aerosol to the hair for 20 seconds. No significant changes occurred in any of various pulmonary function parameters measured, but tracheal mucous velocity decreased by 57% one hour after exposure and in some subjects returned to normal again only after three hours, showing that exposure to hair spray impairs airway defense mechanisms. Since his experiments involved non-habitual hair spray users given a single exposure, no data was presented on possible effects of long-term use.

The California Department of Consumer Affairs (1982, p. III.G.3) reports that complaints of headaches, nausea, shortness of breath, eye and throat irritation, skin rashes, burns, lung inflammation, liver damage and cardiac arrhythmias have been attributed to normal aerosol use.

Methylene chloride is used as a propellant in some aerosols, and it as well as nitrous oxide have an anaesthetic effect on the central nervous system. Methylene chloride is metabolized into carbon monoxide, which can be dangerous particularly to persons with cardiovascular impairments. Methylene chloride is also a component of some paint strippers.

Discussion:

See also Section 1.2.18 "Various Organic Vapours" and Section 1.5.8 "Use of Household Chemicals" for further information. The above section has concentrated primarily on household products that enter the air in aerosolized form, but there is considerable overlap with other sections because many of the contaminants released are common to other types of products as well.

1.2.14 Other Suspended Particulates

Description:

Tobacco Smoke (discussed in detail in a previous section) is the major contributor to indoor respirable particles. Indoor air also contains a broad array of mould spores, fungi, algae, actinomycetes, anthropod fragments, and dusts all of which may evoke human allergic responses. Other elements and compounds such as lead, nitrates, and sulphates are also found (National Research Council U.S., 1981, p. II-6).

Indoor air may in addition contain respirable inorganic fibers including zeolites and comminuted talcs, and respirable man-made mineral fibers including mineral wools and ceramic fibers, respirable organic fibers, and non-fibrous organic particulates. (Bernstein, 1980) Aerosol particles containing sulphur, lead, bromine and iron may also infiltrate dwellings from outside air (from combustion sources including automobile exhaust), and particles containing potassium may also be present (from indoor activities such as cooking and from presence of people (Moschandreas, Winchester et al, 1979, pp. 1413-1417).

Particulates are usually categorized according to size (Young, G.S., 1981, p. 2-3):

respirable (lt. 10 microns diameter) e.g. tobacco smoke, oil smoke

non-respirable (gt. 10 microns diameter) e.g. large particles of fly ash

(1 micron = 10^{-6} metre)

Major Sources:

Household products, cloth, rugs, wallboard, humans, rodents, pets, insects, plants, fungi, humidifiers, air conditioners, gas stoves, fireplaces, gas and oil furnaces, space heaters, condensation of volatiles, aerosol sprays, resuspension of dusts, cooking, and vacuuming (National Research Council U.S., 1981, p. I-8,9, II-4, and Hollowell, 1981. p. 4).

Outdoors suspended particles are formed by the grinding and atomization of solids and liquids or by dispersion of fine powders from bulk sources into the air. Automobile exhaust, smelting operations, ore crushing and grinding contribute lead, other metals, and fine dusts (Young, G.S., 1981, p. 2-3).

Bernstein (1980) reports that inorganic fibers may be brought into the home from industrial exposures on the clothes of a family member, or they may be shed from consumer products or building materials during installation or use in the home (e.g. rock wool or fiberglass fibers).

Non-fibrous dusts include potentially hazardous inhalants such as talcs, attapulgite or other clays (e.g. in kitty litter), and silaceous dusts from plaster, spackling compounds and cement. Road dusts may also contain free silica.

Respirable organic fibers not already discussed under 'house dust' include cotton, grain, tea, wood, and other vegetable dusts, as well as animal dander or feathers.

Concentration Range:

Respirable particles (lt. 10 microns diameter) range in concentration from 100-500 mcg/m^3; this is very much greater than outside concentrations (National Research Council U.S., 1981, p. I-8).

Fine particles (lt. 2.5 microns diameter) range in concentration from 10-260 mcg/m^3 in 2h-hour samples. (The higher concentrations were associated with smoking.) (National Research Council U.S., 1981, p. I-8)

The typical indoor range for TSP (Total Suspended Particles - all sizes) is 30-100 mcg/m^3 averaged over 24 hours, with maximum readings of 600 mcg/m^3. The indoor/outdoor ratio (for TSP) typically varies from 0.3 to 4 (National Research Council U.S., 1981, p. I-8).

Standards:

Canadian Ambient Air Quality Standards for suspended particulate matter (from Statute Revision Commission, 1978a):

	desirable range (in mcg/m^3)	acceptable range (in mcg/m^3)
average over 24 hours	—	0 to 120
annual geometric mean	0 to 60	60 to 70

There are no U.S. federal standards for respirable suspended particulates. The OSHA (Occupational Safety and Health Agency) sets an 8-hr. TWA (time-weighted average) limit of 5000 mcg/m^3 for respirable inert or nuisance dust. (Young, G.S., 1981, P. 2-14)

TSP (Total Suspended Particles) - United States - 24 hr. ambient quality standard (not to be exceeded more than once per year) is 260 mcg/m^3. (National Research Council U.S., 1981, p. I-8, and Young. G.S., 1981, p. 2-14) The U.S. standard for annual geometric mean is 75 mcg/m^3 (Calabrese, 1978b).

Incidence:

Young et al (1981, p. 2-14) listed the following results from the work of others for indoor particulate concentrations:

1) 20-48 mcg/m^3 Respirable Suspended Particulates (RSP) with 30 mcg/m^3 annual arithmetic mean (Spengler, 1979)
1) 8-35 mcg/m^3 24 hr. measurements of Respirable Suspended Particulates (RSP) in 8 homes without smokers (Moschandreas, 1978)
2) 46-85 mcg/m^3 24 hr. measurements of Respirable Suspended Particulates (RSP) in 6 homes with smokers (Moschandreas, 1978)
3) 20-40 mcg/m^3 mean Respirable Suspended Particulates (RSP) over 7 weeks of personal sampling with 46 subjects (Moschandreas, 1978)
4) 30-100 mcg/m^3 Total Suspended Particulates (TSP) (Moschandreas, 1978)
5) 103-108 mcg/m^3 Total Suspended Particulates (TSP) (Yocom, 1970)

Readers are referred to the background references for the detailed conditions involved in each study.

Lead in residences is typically low, less than 0.5 mcg/m^3. Levels as high as 2 mcg/m^3 are measured in houses with leaded wall paints or near major traffic arteries (National Research Council U.S., 1981, p. II-6). (See also Sections 1.5.7 "Intrusion of Outdoor Pollutants" and 1.5.11 "Paints and Sealers" for further discussion of the presence and effects of lead in indoor air.)

Health Effects:

The health effects of tobacco smoke, moulds and house dust have been discussed in previous sections.

Particulate agents such as those described above may cause acute, sub-acute and/or chronic diseases depending on the specific agent and the intensity, frequency and duration of exposures. Mineral wool and glass fibers, silaceous dusts, organic dusts and chemicals absorbed in them can irritate the mucous membranes of the digestive and upper respiratory tracts, as well as the skin and eyes. Low-level intermittent exposures may trigger or exacerbate chronic obstructive lung diseases in susceptible individuals. Some particulates possess immuno-sensitizing activity which can induce allergic responses in susceptible individuals (e.g. vegetable dusts, animal dander, pollens, wood dusts). Further research is required to confirm whether some (e.g. fibrous glass, wood dust) can act as carcinogens. (Bernstein, 1980)

The U.S. National Research Council (1981, p. ES-7) states that man-made fibers have produced skin irritation, but have not otherwise been demonstrated convincingly as hazardous to health.

Sterling et al (1981) note that small particles found in indoor air tend to have a large concentration of organic fractions, and in particular a higher concentration of benzene than is found outdoors. They conclude that the indoor particles have a greater carcinogenic potential than do outdoor particles.

Discussion:

Young (1981) cautions that there are problems relating measured levels to personal exposure. An additional problem for particulates is that the toxic effects will vary depending upon the size and chemical nature of the particles (Young, G.S., 1981, p. 2-14).

Brookman & Birenzvige (1980, p. 7) note that in a series of studies measuring total suspended particulate matter in a low volume sampler, the average indoor/outdoor ratios ranged from 0.15 to 1.3, and that indoor concentrations were lower than outdoors in most cases. They note that in another series of studies measuring particles by number concentrations, the indoor/outdoor ratios of number concentrations varied from .45 to 3.8. The relative contribution of small particles in the respirable range (less than 2-3 microns in diameter) is greater indoors, particularly in the presence of air conditioning, which removes larger particles but not smaller ones.

Lawrence Berkeley Laboratory researchers have observed levels of respirable particulates from indoor combustion sources, frequently comparable to those present outdoors on a very smoggy day (Hollowell, 1981, p. 5).

1.2.15 **Pesticides**

Description:

Pesticide contamination inside the home can occur from migration of gases from beneath the home (e.g. where subslab termite treatment has been done) or from direct application for fumigation or regular extermination. Spray drift from aerial spraying or from neighbouring lawn or farm spraying can also contaminate the interior of a home. Numerous household products also contain pesticides.

Savage et al (1979) reported that pesticides are widely used in the United States in the home environment and that such usage may result in environmental and human problems, particularly due to misuse and overuse of toxic compounds. In 8254 households responding to a U.S. survey, 90.7% indicated that pesticides were used in their house, garden or yard. Some 83.7% of all responding households used pesticides in the house, 21.4% in the garden, and 28.7% in the yard. House use included the use of retail pesticide products such as no-pest strips and mothballs, the use of pet insecticide products, or the employment of a commercial pesticide applicator. 253 of the respondents stated that they or some member of their household experienced dizziness, headache, nausea or vomiting after using pesticides. Twenty-two respondents said that they or another member of their household experienced severe adverse effects related to pesticide use and were treated by a physician.

Concentration Range:

Ulsamer et al (1980) quote U.S. EPA residential monitoring data for the most frequently found pesticides and their concentrations in U.S. homes:

chlordane	0.1-10 mcg/m^3	DDVP	0.5-10 mcg/m^3
ronnel	0.2-2 mcg/m^3	malathion	0.2-2 mcg/m^3
dursban	0.2-2 mcg/m^3	diazinon	0.2-2 mcg/m^3

The pesticides listed are organothiophosphates except for DDVP, which is an organophosphate, and chlordane, which is an organochlorine compound. Some of the above may be either less common or not used at all in Canada. For example, there is only one registered ronnel domestic class pesticide product in Canada. In addition, chlordane is not normally used inside dwellings in Canada at present, and it can be applied only by licenced operators (Health & Welfare Canada, 1983, private communication).

Standards:

Because of the existence of documentation on chlordane incidence (see below), it will be taken as an illustrative example.

Chlordane was first developed in 1945 and was widely used at least in the United States for agricultural and household pest control until 1975 when the U.S. Environmental Protection Agency restricted its use to termite control and the dipping of roots and tops of certain non-edible plants (Environmental Protection Agency, 1976, as reported in Lillie, 1981). The restriction was justified by the high persistence of chlordane in the environment and the discovery of degradation products of chlordane in food, human tissue and wildlife.

The National Academy of Sciences (1979, as reported by Lillie, 1981) recommended a level of 5 mcg/m^3 as acceptable in the home, but in doing so, stated that it "... could not determine a level of exposure to chlordane below which there would be no biological effect under conditions of prolonged exposure of families to housing". A continuous exposure level of 500 mcg/m^3 is the maximum allowable limit in an occupational setting for an eight-hour day, five-day week (American Conference of Government Industrial Hygienists, 1979, as reported in Lillie, 1981).

Incidence:

Livingston and Jones (1981) presented an interesting example of ongoing contamination of indoor air by pesticides. Measurements of chlordane insecticide vapour were taken in U.S. Air Force apartments (ground-floor) with intra-slab or sub-slab heating ducts, and in which 2% chlordane had either been injected under the slab or applied by soil drench before pouring the slab, for termite control.

In one of their surveys, in 1979, all apartments which had been treated three months earlier showed high concentrations of chlordane in the living space, with a range of 0.4 to 263.5 mcg/m^3. Random samples of other apartments including some treated in earlier years, and some untreated, yielded a range of 0.0 to 7.4 mcg/m^3, with an average of 1.55 mcg/m^3. Some 60% of the apartments had concentrations greater than 1.0 mcg/m^3.

Except for the apartments treated in 1978, three months before the survey, there was no correlation between chlordane concentration and year of treatment. In fact, in 4 apartments with levels of 4 mcg/m^3 or greater, treatment had taken place in 1977, 1973, 1969, and 1964. Two apartments above the ground floor showed concentrations of 0.6 and 3.6 mcg/m^3, indicating some upward movement of the contaminant. The untreated apartments showed no detectable contamination.

Livingston and Jones also report a survey of 498 apartments in 1980, (87% of which had been reported as treated) which yielded a range from 0.0 to 37.9 mcg/m^3 of airborne chlordane, and an average concentration of 1.9 mcg/m^3. There were 362 apartments, or 72.6% of the sample, that had detectable chlordane levels (above 0.02 mcg/m^3). The six highest concentrations (ranging from 14.5-37.8 mcg/m^3) were found in buildings treated in 1970.

Livingstone and Jones (1981, p. 408) note that four houses in the 1979 U.S. Air Force Survey cited above had airborne chlordane concentrations greater than 20 mcg/m^3. These apartments were modified by sealing the subslab ducts, thoroughly cleaning walls and floors and installing new furnaces and ceiling air ducts. Although not stated in the references, it can be inferred that levels greater than 20 mcg/m^3 were considered by the U.S. Air Force to represent a significant health hazard.

Lillie (1981) reports that in fact, the U.S. Department of Defense has begun inventories of all termiticide-treated buildings with sub- or intra-slab heating or cooling ducts, and has ordered corrective action for any houses exceeding the 5 mcg/m^3 level. The U.S. Environmental Protection Agency is preparing a risk/benefit analysis of several chemicals registered for termite control.

Health Effects:

Henkin (1974, p. 207-8) notes that cases of poisoning have been reported for practically every insecticide, which suggests that particularly under conditions of misuse this category of chemicals could represent a danger when applied in and around the home. The chlorinated hydrocarbon and organophosphate insecticides are the two most prevalent groups causing toxicity. The chlorinated hydrocarbons are relatively stable in the environment, are not easily biodegradable or readily metabolized, and persist in the body for long periods of time, stored in body fat tissues. The mode of entry includes the respiratory tract, the digestive tract, and the skin or mucous membranes. The insecticides can be divided into three main groups:

(1) DDT, lindane, methoxychlor, etc.
(2) aldrin, dieldrin, chlordane, etc. (polycycloaliphatic insecticides)
(3) simple chlorinated aliphatic hydrocarbons

Henkin notes that mild toxicity is generally characterized by headache, dizziness, numbness and weakness of the extremities, apprehension and hyperirritability. When large amounts are absorbed, symptoms may include fine muscular tremors that spread from the head to the extremities, jerking movements that involve whole muscle groups, loss of equilibrium, and finally convulsions. Where death is involved at high doses it is usually due to cardiac failure or respiratory collapse.

The California Department of Consumer Affairs (1982, p. III.I.41) reported that a study of chronic pesticide exposure effects in Hawaii correlated frequent home use of pesticides with respiratory impairment as measured by spirometry, and with clinical histories of asthma, chronic bronchitis and sinusitis. The pesticides used by the individuals tested contained dichlorvos, dieldrin, and petroleum distillates.

The first neurological symptoms of organophosphate poisonings are anorexia, nausea, and headache. These are followed by salivation and papillary constriction, and in severe cases convulsions, coma and death may occur. These substances include many commonly used chemicals such as parathion and diazinon (Henkin, 1974, p. 208).

Chlordane produces blurred vision, confusion, ataxia, cough, abdominal pain, nausea, vomiting, headaches, dizziness, and mild chronic jerking.

Chlordane has also produced cancer in mice (Ulsamer et al, 1980). Captan causes birth defects in animals (Beall and Ulsamer, 1981, p. 984).

Lillie (1981) reports that the epidemiological literature includes an examination of workers exposed to 1.2 to 1.7 mcg/m^3 for 1-15 years, showing no job-related illness among the workers, and a similar conclusion as a result of a study of workers exposed to 5,000 mcg/m^3 for three years. Notwithstanding, The U.S. Department of Defense has announced corrective action for houses exceeding the 5 mcg/m^3 level.

Herbicides in general have been observed to produce local mucous membrane irritation, including the eyes, and some muscular disturbances. They may also produce fever. These substances include such commonly used agents as 2,4-D, silvex and dinitrophenols. Fungicides such as maneb and ferbam produce toxic effects similar to those observed with pesticides (Henkin, 1974, p. 208).

Pesticides appear to be potent sensitizing chemicals and one of the more significant hazards to people who are already susceptible to a wide range of chemicals at low exposure levels (Morgan, 1981).

Butler et al (1982) analyzed blood samples of 40 hospitalized patients for pesticide content, and found that 39 out of 40 had measurable pesticide levels in their blood. Pesticides found were BHC (alpha, beta and gamma), Chlordane, DDT, DDE, Endosulfan I, Endosulfan sulphate, Endrin, Heptachlor, Heptachlor epoxide and Hexachlorabenzene. The most common pesticides were DDT and Hexachlorabenzene. Many in the same group showed abnormal immunological fluctuations in T and B cell production, and demonstrated cerebral dysfunctioning and disorders of personality at pathological levels. The authors have proposed additional studies to determine the incidence of pesticides in the blood in a nonhospitalized population and to determine whether the presence of pesticides is connected with immune system, behavioural and psychological abnormalities.

In Canada, DDT and parathion are restricted pesticides that may be used only by professional pest control operators (Health & Welfare Canada, 1983, private communication).

1.2.16 **Ammonia**

Description:

Ammonia (NH3) is a highly irritating gas with a strong pungent odour. When it comes in contact with the moisture of the throat and bronchi it forms ammonium hydroxide, which is strongly alkaline (Waldbott, 1973, p. 94).

Major Sources:

Human metabolic activity (Hollowell, 1981, p. 4).

Outdoor sources include combustion of fuels, incineration of waste products, the internal combustion engine, chemical plants, coke ovens and refineries. In stock yards ammonia is formed by biological degradation. However, the main atmospheric source of ammonia is from natural processes on land and in the oceans (Henkin, 1974, p. 195).

Approximately 85% of ammonia is applied by farmers to the soil as anhydrous ammonia fertilizer (Waldbott, 1973, p. 94).

Household cleaning products are a major indoor source of ammonia.

Concentration Range:

Outdoor atmospheric concentrations in the temperate zones are about 6 mcg/m^3, and about 140 mcg/m^3 near the equator. Average urban concentrations are around 20 mcg/m^3 (Waldbott, 1973, p. 94).

Standards:

Proctor and Hughes (1978, p. 101) note that the Threshold Limit Value (U.S.) for ammonia in industrial situations is 25 ppm (17,000 mcg/m^3), set at this level to prevent irritation to the eyes and respiratory tract. They note that in mild exposure resulting in mucous membrane irritation, the symptoms may mimic a viral upper respiratory tract infection, characterized by fever, myalgias, and lymphocytosis.

Incidence:

No residential measurements were found during the the literature search.

Health Effects:

Henkin (1974, p. 195) reports that inhaled ammonia is an irritant that affects primarily the upper respiratory tract, and ammonia sulphate aerosols have been responsible for irritant effects in several severe smog episodes. If ammonia concentrations are high or exposure prolonged, the eyes may be seriously damaged, with resultant chemosis, infiltration opacities of the cornea, iritis and cataracts. Sneezing and salivation have also been reported following exposure to ammonia.

Waldbott (1973, p. 94) reports that at concentrations of 280 to 490 mcg/m^3 the gas produces slight irritation of the eyes and throat as well as a hoarse voice. Higher concentrations (1700 - 4500 mcg/m^3) are known to induce pulmonary edema.

Discussion:

Instituut voor Milieuhygiene (1976, p. 3) reports that ammonia is adsorbed onto various building surfaces and fabrics. These include:

painted wall surface
hardwood
softwood
cardboard
wall-paper
wool
nylon
cotton

The researchers conclude that in the event of release of ammonia (e.g. through a transportation accident) that adsorption of ammonia by building materials and fabrics will reduce the ultimate potential indoor concentration significantly. In a special test chamber the concentration reached in the presence of clothing materials was 51% of the ultimate concentration reached in the empty chamber, and with hardwood the concentration reached was only 34% of the ultimate concentration in absence of the hardwood.

While adsorption of gaseous contaminants can be advantageous in the presence of pollution sources, such adsorbers often become sources themselves when primary sources are removed or decline in strength (Godish, 1982) and subsequent long periods of low exposures should not be ignored when estimating total occupant exposure.

1.2.17 **Chlorine**

Description:

Chlorine (Cl2) is a green-coloured gas (at high concentrations) with a sharp odour. When it reaches the lung it combines with the hydrogen of water to form hydrochloric acid (HCl) which is highly corrosive (Waldbott, 1973, p. 92).

Major Sources:

Outdoor sources of chlorine include industrial processes involving the electrolysis of alkali chloride solution. It may also escape into the atmosphere during the liquefaction process prior to storage (Henkin, 1974, p. 196).

Indoor sources include swimming pools and municipal water supply. McCarthy et al (1981) also report that cigarette smoke, coal and wood smoke, and a number of household aerosol products such as certain room deodorants, bathroom cleaners, bug killers, hair sprays and personal deodorants all contain chlorine.

Gosselin et at (1976) report that chlorine may be present in household liquid bleaches in the form of sodium hypochlorite, in proportions up to 10% by weight. Chlorine type powder bleaches contain organic chlorine in the form of salts of dimethyldichlorohydantoin, dichloroisocyanuric acid, and others in proportions up to 20% by weight.

Chlorine in concentrations released from treated indoor swimming pools can affect chemically susceptible persons, and the vapours from such installations can in some cases permeate an entire house.

Standards:

The industrial threshold limit value for chlorine in the United States is 1 ppm (3000 mcg/m^3) for an 8 hour day (Waldbott, 1973, p. 92).

Incidence:

No residential data was found in the literature search.

Health Effects:

Chlorine is an irritating and corrosive gas which affects the mucosa of the eyes and upper respiratory tract, as a result of its strong oxidizing action on the sensory receptors in the mucous membranes. Noticeable irritation has been reported at levels of 3000 mcg/m^3 (1 ppm) or less. There are also reports that people chronically exposed to chlorine can develop some degree of tolerance. Headaches have been reported to be caused by irritation of the nasal sinuses. Sneezing, coughing, loss of voice, dizziness, anxiety, syncope anorexia, profuse tearing, and photophobia have also been reported. Reports of odour threshold range from 150 to 940 mcg/m^3 (.05 to .3 ppm) (Henkin, 1974, p. 196).

Rea, Bell et al (1978, p. 55) report that vapour caused by the presence of chlorine compounds in municipal tap waters, particularly in showers and bathtubs, is sufficiently concentrated to adversely affect chemically susceptible people.

Discussion:

The California Department of Consumer Affairs (1982, p. III.G.7) cautions that bleaches must never be mixed with drain or oven cleaners which contain ammonia. The mixing of chlorine bleach and ammonia creates deadly chloramine fumes. Mixing bleach with vinegar or certain toilet bowl cleaners also produces poisonous chlorine gas.

1.2.18 Various Organic Vapours

Description:

In addition to the specific gases described in the preceding sections, there are a large number of organic contaminants, usually all at relatively low concentrations, that are present in indoor air.

Hollowell and Miksch (1981, p.5), in a gas chromatography-mass spectrometry analysis of a typical office environment, found organic contaminants in greater number and concentration indoors than outdoors. Largest peaks fell into three main classes of compounds:

1) aliphatic hydrocarbons including straight-chain and derivatives of cyclohexane. These hydrocarbons are derived petroleum distillate-type solvents.

2) alkylated aromatic hydrocarbons, predominantly toluene, but also including xylenes, trimethyl-and other substituted benzenes, and methyl- and dimethylnaphthalenes. These compounds are either solvents themselves or constituents of naphthenic-type petroleum solvent mixtures.

3) chlorinated hydrocarbons, predominantly tetrachloroethylene, 1,1,1, trichloroethane and trichloroethylene.

(The term hydrocarbons comprises a wide variety of compounds whose molecules consist of atoms of hydrogen and carbon exclusively. They occur as gases, liquids, or solids. Hydrocarbons with 1 to 4 carbon atoms are gaseous at ordinary temperatures, whereas those with 5 or more carbon atoms are liquids or solids. Acyclic hydrocarbons are those hydrocarbons in which the carbon atoms are arranged in chains with or without branching chains, but without rings. Aromatic hydrocarbons are those hydrocarbons in which the atoms are arranged in benzene rings, i.e. in six-membered carbon rings with only one additional atom of either hydrogen or carbon attached to each atom in the ring. Alicyclic, or cycloaliphatic hydrocarbons consist of saturated cyclic systems (e.g. cyclopentane, with a ring of five carbon atoms, each bonded to two additional hydrogen atoms (Waldbott, 1973, p. 233))

Miscellaneous other compounds observed were ketones, aldehydes and benzene. Although concentrations may be different, this set of pollutants may also be typical of residential environments. Hollowell and Miksch (1981, p.5) attributed the contaminants to:

new building materials
aged building materials
wet-process photocopiers
smokers
building maintenance products

1.2.18 Indoor Air Pollutants: Various Organic Vapours (continued)

Johansson (1977, p. 1371) found in schoolroom measurements that aliphatic and aromatic hydrocarbons were predominant, followed by the halogenated hydrocarbons and a few other compounds such as acetone and ethanol. His study detected 160 compounds, mainly hydrocarbons, indoors compared to 50 organic compounds outdoors. Concentrations were always found to be higher indoors than outdoors and to increase when people were present in the room.

Major Sources:

Various organic vapours are produced by indoor combustion, tobacco smoking, cooking, and use of aerosols, cleaning agents and hobby materials. They also outgas from synthetic organic building materials and furnishings, solvents, adhesives, paints, resin products, and pesticides. (National Research Council U.S., 1981, p. I-8, II-5, ad Hollowell, 1981, p. 4)

Finkel et al (1979) also report organic compounds emitted from carpet, fiber and fabric samples. Hollowell & Miksch (1981, p.6) note a continuous emission rate of 1.0 mg/ft^2 of organic compounds for wall-to-wall carpeting after several months. The use of consumer products (aerosols, deodorizers, cleansers and coatings), pesticides, and craft materials within the home also contribute to the levels of organic vapours, as does cooking (Beall and Ulsamer, 1981, p. 978).

The California Department of Consumer Affairs (1982, p. II.N.1) reports that the degreasing agents and sealants used in sealing polyvinyl chloride plumbing pipes contain various organic solvents which have caused symptoms in those applying them. The formulations examined contained methyl ethyl ketone (MEK), dimethylformamide (DMF), cyclohexane (CH) and tetrahydrofuran (THF). These are often used by householders themselves, and exposure continues for some time after initial curing of the solvent glue in the pipe joints.

Sterling et al (1981) note that many paints, floor waxes, and a wide variety of plastics give off carbon monoxide steadily, along with a variety of other hydrocarbons. They refer to these as products of slow combustion, or oxidation-reduction reactions.

Concrete releases a variety of gases and odours at low concentrations, particularly when wet, although the mix and mechanism by which these are produced is not well understood (Sereda, 1977).

Hollowell & Miksch (1981, p. 6) state generally that new building materials are a source of organic contaminants because they contain residual solvents and other compounds remaining after the process of manufacture. Qualitative gas chromatography-mass spectrometry analysis of the headspace vapour standing over a variety of new building materials revealed a great number of organics, predominantly toluene and aliphatic hydrocarbons. Ketonic solvents, esters, aromatic hydrocarbons and formaldehyde were observed as well as specialty compounds such as butylated hydroxytoluene (BHT).

Molhave (1981) investigated 42 Danish building materials for emission of organic gases and vapours. Surface materials like carpets, wall paper, paints, etc. made up 67% of the materials. Tightening, sealing or puttying materials represented 14%, and 19% were materials normally hidden within the the house construction, such as concrete and insulation materials.

The average rate of emission of organic compounds was 0.25 mg/m^2 per hour. The average number of compounds detected from each sample was 22. From 42 air samples, 62 compounds in all were identified, and they did not differ from those found in previous measurements directly in homes. Some 47% of the identified compounds were alkylbenzenes, alkanes represented 28%, and only 13% were not ordinary hydrocarbons. Positive indications were found of aldehydes for 3 materials, and amines for two materials. Most of the air samples were unacceptable to an evaluating panel, and only two samples did not emit detectable odours. Some 42 of the 62 compounds identified by Molhave are known as or suspected to be airway-irritants, and although none were recognized human carcinogens, 15 are mentioned in a 1976 NIOSH list of suspected carcinogens.

The work of Johansson (1977, p. 1376) showed that human beings are also a significant source of organic emissions. The human breath contains an average of 1200 mcg/m^3 of acetone and 240 mcg/m^3 of ethanol at 20 degrees C and 1 atmosphere. Acetone and ethanol measurements reached averages of 24 and 55 mcg/m^3 respectively in schoolroom measurements while people were present, approximately twice the levels for unoccupied rooms. At least part of the increase for ethanol was presumed to be due to perfume and deodorant, in addition to breath emissions.

Hollowell and Miksch, (1981, p. 14) summarize the sources of a few of the major organic contaminants in Figure 5 on the following page. Ulsamer et al (1980) list several more categories and their common uses (reproduced in Figure 6).

MacLeod (1979, p. iv and 1981, p. 926) reports that prior to cessation of production of PCBs in 1977, many of the products containing PCBs were for indoor use, and included: textile dyes, printing inks, paints, carbonless copy paper, pesticides, plastics, lubricants, waxes, adhesives, fireproofing agents, and small electrical capacitors and transformers, as well as fluorescent light ballasts. Defective light ballasts manufactured prior to 1972 emitted large quantities of PCB and were considered to be an important source, as were capacitors in small electrical equipment.

Verberk and Scheffers (1979, p. 436) demonstrated in an Amsterdam study that emission of tetrachloroethylene from dry-cleaning shops resulted in an absorption of this substance by neighbours both above and adjacent to the shops. This substance will also be emitted by freshly-dry-cleaned clothing brought into other homes. Tetrachloroethylene measured in alveolar (lung sample) air in the study varied from none detectable (across the street from the shops) to a high of approximately 40 mg/m^3 measured in one resident immediately above the shop. The geometrical mean for workers exposed in the shops was 73 mg/m^3.

Figure 5: Various Organic Chemicals and Their Uses (Hollowell and Miksch, 1981)

Compound	Sources and/or Uses
formaldehyde	building materials such as particleboard, plywood, and urea-formaldehyde foam insulation; cooking; smoking
Cn alkanes and Cn alkenes n=5-16	gasoline, mineral spirits, solvents
Benzene	plastic and rubber solvents; cigarette smoking; used in paints and varnishes, including putty, filler, stains and finishes
Xylene	used as solvent for resins, enamels, etc.; also used in unleaded automobile fuels and in manufacture of pesticides, dyes and pharmaceuticals
Styrene	widely used in the manufacture of plastics, synthetic rubber and resins
1,1,1 trichloroethane	aerosol propellant, pesticide, cleaning solvents
trichoroethylene	oil and wax solvents, cleaning compounds, vapour degreasing products, dry cleaning operations, also used as an anaesthetic
ethyl benzene	solvents; used in styrene-related products
chloro benzenes	used in production of paint, varnish, pesticides, and various organic solvents
polychlorinated biphenyls (PCBs)	used in various electrical components, esp. transformer oil; may appear in waste oil supplies and in plastic and paper products in which PCBs are used as plasticizers
pesticides	used for insect control

Figure 6: Categories of Chemicals and Common Uses (from Ulsamer et al (1980)

Ketones: as solvents in lacquers, varnishes, lacquer and varnish removers, lubricating oils, adhesvies, cosmetics and perfumes.

Ethers: as solvents for resins, paints, varnishes, lacquers, dyes, soaps and cosmetics.

Esters: used in plastics, resins, plasticizers, lacquer solvents, flavours and perfumes.

Pentachlorophenol: used as a preservative for wood, wood products, starches, dextrins and glues. PCP has been found in human tissues, with inhabitants of log homes having higher tissue concentrations than the general population (0.39 ppm blood levels vs. 0.04 ppm). Air levels in log homes have ranged from 4 mcg/m^3 to 1000 mcg/m^3. PCP can cause lung, liver and kidney damage and is currently being tested as a possible carcinogen.

Polymer components: in building structures, furniture, packing systems, clothing, and other products. These polymers contain unreacted monomers and contain other chemicals such as plasticizers, stabilizers, fillers, colorants, and antistatic agents.

Monomers: (e.g. vinyl chloride, esters of acrylic acid, epichlorohydrin, and toluene di-isocyanate) may be released from various polymers. Esters of acrylic acid are used to prepare a large class of plastics referred to as the acrylics. Epichlorohydrin is used in the synthesis of a number of epoxy resins, and is carcinogenic, as is vinyl chloride. Toluene di-isocyanate is used in the synthesis of polyurethane.

Plasticizers: used to provide flexibility and as a processing aid to convert a polymer into a final plastic product. Alkyl phthalates constitute the major portion of the U.S. plasticizer market. Others include epoxy esters, phosphates, adipates, polyesters, trimellitates and dibenzoates.

Stabilizers: organotin compounds are used as stabilizers for vinyl plastic.

Other Chemicals in Plastic: a number of other chemicals used as curing agents and accelerators may also be of interest. These are diethyltetramine, mercaptobenzothiazole, tetramethylthiuram, monosulphide, and diphenyl guanidine among others. Anti-oxidants added to polymers such as the monobenzylether of hydroquinine and phenylbeta naphthylamine may also be possible indoor pollutants.

Gosselin et al (1976) indicate that polyurethane foams consist of a diisocyanate (often toluene di-isocyanate), a polyol, a catalyst (sometimes aliphatic amines), a blowing agent (often a chlorinated hydrocarbon), and frequently a catalyst accelerator (consisting of tin compounds). Waldbott (1973, p. 190) reports outgassing of small quantities of toluene diisocyanate from polyurethane products - rigid foam, flexible foam, and surface-coating products.

Concentration Range:

Indoor concentrations measured have been generally greater than outdoor concentrations during 90% of monitored hours, and range from 0 to 8.0 ppm in total non-methane hydrocarbons (National Research Council U.S., 1981, p. I-8, II-5). Typical outdoor concentrations range from 0 to 3.5 ppm in non-methane hydrocarbons (National Research Council U.S., 1981, II-5).

Individual organics appear to be in the range of 1-100 ppb.

Standards:

OSHA* PELs (Permissible Exposure Limit) for industrial situations are (from Hollowell & Miksch, 1981, p.13):

various hydrocarbons (n-hexane, n-heptane, n-octane, methyl-cyclohexane	500 ppm
benzene	1 ppm
xylenes	100 ppm
toluene	200 ppm
trichloroethane	350 ppm
trichloroethylene	100 ppm
tetrachloroethylene	100 ppm
methylethylketone	200 ppm

*OSHA = U.S. Occupational Safety and Health Administration

Calabrese (1978b, p. 289) reports that the U.S. Environmental Protection Agency Ambient Air Quality Standard for hydrocarbon is a three-hour maximum 6-9 a.m., of 160 mcg/m^3 or 0.24 ppm.

Macleod (1979, p.3,4) reports a proposed U.S. National Institute for Occupational Safety and Health criterion of 1 mcg/m^3 for all carcinogens including PCBs. At that time the existing U.S. Occupational Safety and Health

Agency (OSHA) standard for a safe workplace environment was 1 mg/m^3 time-weighted average permissible air concentration of PCB for an 8-10 hour workday, 40 hr. work week.

The applicability of the above standards to the residential situation is questionable.

Incidence:

Molhave (1979, p. 90) measured organic gases and vapours in 14 rooms where occupants were complaining about severe non-thermal indoor air problems. A majority of the complaints were related to mucous membranes and upper airways. The average concentration of organic gases was 0.95 mg/m^3, and that of dust was 0.07 mg/m^3. About 50% of the 29 different compounds identified in the gas samples were alkylbenzenes, and the remaining were alkanes (20%), terpenes (9%), and others 16%, with 5% partial identifications. The concentrations of organic gases and vapours exceeded the US outdoor air standard of 0.13 mg/m^3. It was noted, however, that this standard is related to the production of photochemical oxidants and may have no relevance indoors. The concentration of dust exceeded the US outdoor standard of 0.06 mg/m^3.

Toluene and 3-xylene were seen in more than 50% of the room samples, and alpha-pinene, undecane, ethanol, ethylbenzene, 1,1,1,trichloroethane, and benzene were found in more than 20% of the samples. The highest average concentrations were measured for ethanol and toluene (0.68 and 0.61 mg/m^3 respectively).

From comparison with gases measured in the headspaces above 32 construction materials in test chambers, Molhave concludes that the compounds measured in the 14 indoor locations probably originated from construction materials. The material samples yielded toluene in more than 50% of the samples. Decane, xylene, undecane, 1,2,4,trimethylbenzene, propylbenzene, ethylbenzene, and nonane were identified in more than 20% of the samples.

In similar measurements of organic gases and vapours in 7 new Danish homes (age less than 1 month) and 39 older homes (between 3 and 18 years old), Molhave and Moller (1979, p. 177) found a significant difference between newer and older houses. The average concentration of organic gases and vapours in the new houses was 6.2 mg/m^3. The minimum concentration among these new houses was 0.5 mg/m^3, which is still four times the US standard for hydrocarbons in outdoor air. The older houses averaged 0.4 mg/m^3, or three times the US outdoor standard. Ventilation in the rooms measured varied from 0.1 to 3.9 air changes per hour. Average ventilation rates of 0.3 per hour and 1.3 per hour were found in new and older houses respectively. The authors attributed the higher concentrations of organics in the new houses to both lower ventilation and increased pollutant sources equally.

Work by Hollowell and Miksh (1981, p.4) in office buildings is likely to be somewhat representative of the residential picture, with the exception of the presence of wet-process photocopier machines. In measurements of a typical office containing 40 workers, they found that no pollutants measured, even formaldehyde, exceeded air quality standards individually. The average total hydrocarbon concentration, however, exceeded both outdoor concentrations and ambient air quality standards:

	concentration	
	mcg/m^3	ppm (expressed as methane)
total non-methane hydrocarbon concentration	1627 +/-26	2.5
average outdoor conc.	210 +/-60	0.32
National Ambient Air Quality Standard*	160	0.24

*N.B. This standard was established on the basis of hydrocarbons acting as precursors for photochemical smog, and does not necessarily imply that hydrocarbons themselves are harmful.

Concentrations in new offices range from 10-50 ppm in non-methane hydrocarbons. (National Research Council U.S., 1981, II-5)

MacLeod (1979, p.iv, and 1981, p.926) reports that indoor air, whether in commercial, industrial or residential buildings, contains levels of PCBs at least one order of magnitude higher than outdoor levels, and that despite the fact that PCBs are no longer manufactured in the U.S. exposure to the chemical continues due to the presence of products manufactured up to the early 1970s. Defective fluorescent ballasts were shown to emit PCBs and to be an important source of indoor atmospheric contamination.

In the MacLeod study of residential air sampling, average concentrations ranged from .039-.58 mcg/m^3 of PCBs present indoors, in some cases up to 6 times the average levels found in offices. In every case, the levels of PCB found were higher in the kitchen than in other rooms tested. Four houses out of nine had pre-1972 fluorescent lighting fixtures in their kitchens, but little or no correlation was found between PCB concentration and the type of lighting used. It was assumed that other electrical appliances typically found in kitchens may emit PCBs. The level outside one home was .004 mcg/m^3 while the average level inside on the same day was .31 mcg/m^3. The amounts found indoors are within a NIOSH proposed criterion for a safe workplace atmosphere, of 1.0 mcg/m^3 over an 8-10 hour workday and a 40-hour workweek.

The MacLeod study included observation of a fluorescent ballast burnout in an office environment. Air levels of PCB on the day of burnout were found to be over 50 times higher than normal (11.6 mcg/m^3 vs. 0.2 mcg/m^3 for that room, and levels remained elevated for 3-4 months afterward.

Health Effects:

Little is known of the short and long-term health effects of many of the organic compounds mentioned, at the low levels of exposure that occur in non-industrial indoor environments.

The following table describes briefly the kinds of effects that are found or suspected with significant exposures greater than present industrial limits (information taken from Hollowell & Miksch, 1981, p. 14):

Compound	Health Effects at High Concentrations
formaldehyde	eye and respiratory irritation; cancer risk
alkanes/alkenes	narcotic effect and mildly irritating
benzene	respiratory irritation; mild carcinogen
xylene	narcotic effect and irritating; high concentrations may injure heart, liver, kidneys and nervous system
toluene	narcotic; may cause amnesia
styrene	narcotic; can cause headache, fatigue, stupor, depression, incoordination and possible eye injury
1,1,1-trichloroethane	subject of OSHA carcinogenesis inquiry
trichloroethylene	animal carcinogen; subject of OSHA carcinogenesis inquiry
ethyl benzene	highly irritating to eyes, etc.
chloro benzenes	strong narcotic effect; possible lung, liver and kidney damage
PCBs	suspected carcinogens
pesticides	some are suspected carcinogens

A similar list derived from Beall and Ulsamer (1981) is as follows:

volatile organic solvents generally: lipid solubility of organic vapours assures that they are reapidly absorbed through the lungs and enter organs containing high concentrations of lipid. They rapidly cross the blood-brain barrier and commonly depress central nervous system and cardiac functions.

aliphatic hydrocarbons (such as propane, butane, and isobutane):
- -may cause asphyxia by displacing oxygen from a closed environment
- -n-hexane causes demyelination and degeneration of peripheral nerves.

halogenated hydrocarbons (eg. methyl chloroform and methylene chloride)
- -acute exposure to halogenated hydrocarbons typically causes central nervous system and myocardial depression.
- -some cause cancer in animals: 1,1,2-trichloroethane, hexachloroethane, 1,2-dichloroethane, vinyl chloride, vinylidene, and tetrachloroethylene.
- -vinyl chloride causes cancer in humans

aromatic hydrocarbons (eg. toluene)
- -causes fatigue, muscle weakness, and confusion in humans exposed for 8 hours to atmospheric concentrations of 20 to 300 ppm.
- -also causes central nervous system depression, psychosis, and liver and kidney damage
- -benzene causes local irritation, intoxication, central nervous system depression, and death; also leukemia

alcohols
- -irritate mucous membranes and produce depression of the central nervous system
- -excitation, ataxia, drowsiness and narcosis can be produced at high concentrations.
- -Methanol at high concentrations can affect the retina and cause blindness.

ethers (including methyl, ethyl, and butyl ethers of ethylene glycol, dimethylether, tetrahydrofuran, and dioxane)
- -exposure causes headaches, weakness, drowsiness, disorientation, and lethargy. They are potent central nervous system depressants
- -dioxane (1,2,4) produces skin and eye irritation, liver and kidney damage, and cancer in animals

esters (such as ethyl acetate, butyl acetate, and ethyl butyrate)
- -in high concentrations, irritate the eyes, nose and throat
- -some central nervous system depression

../ (list continued)

(list continued)

polymers
- most nontoxic
- can contain unreacted monomers, plasticizers, stabilizers, fillers, colourants, and antistatic agents, some of which are toxic. These chemicals diffuse from the polymers into the air.

monomers(eg., acrylic acid esters, toluene di-isocyanate, epichlorohydrin, styrene, and vinyl chloride)
- acrylic acid esters can irritate skin, eyes, and mucous membranes
- epichlorohydrin (used in epoxy resins) corrodes mucous membranes in the respiratory tract, and damages DNA
- toluene di-isocyanate irritates the skin, eyes, and respiratory tract and is a strong sensitizer that can induce asthma; high concentrations cause neurological and cerebral effects
- vinyl chloride causes cancer in humans

plasticizers (e.g. alkyl phthalates)
- in general do not elicit excessive acute toxicity unless exposure to them is great
- some phthalate esters cause chromosomal and teratogenic effects in animals
- di-(2-ethylhexyl) phthalate (DEHP) and di-(2-ethylhexyl) adipate cause cancer in rats and mice

other chemicals in plastics
- organotin compounds irritate tissues and cause neurological changes.

pentachlorophenol
- illness has been reported in PCP-treated homes in California and Kentucky, USA

Macleod (1979, p.2) reported that accidental contamination of rice-bran oil by PCB in a 1968 Japanese incident gave rise to chloracne, eye discharges, hyperpigmentation of skin and nails, swelling of upper eyelids, and still-birth, among 1000 people of all ages affected.

Verberk and Scheffers (1979, p. 436) note that at moderate concentrations of between 700 and 1500 mcg/m^3, tetrachloroethylene can cause irritation of the mucous membranes of the eyes and upper respiratory tract, headache, dizziness, and slight unconsciousness, but also point out that no data are available on the effects at lower concentrations.

Waldbott (1973, p. 190,191) reported the effects of long-term inhalation of minute amounts of toluene diisocyanate (TDI) to be those of typical allergic asthma, often associated with allergic eye and nasal symptoms as well as hives and dermatitis. Pulmonary function studies of workers exposed to less than 0.02 ppm indicate that frequent exposures have a cumulative action, and that significant impairment of lung function can occur in spite of only minor, or even lack of other symptoms. The asthma following exposure can be a true allergic type, as antibodies specific for TDI have been found. Sensitivity to TDI can be induced with no prior history of allergy, and may contribute to an overall sensitivity to other antigens.

Pepys (1981) notes that vapours and fumes from the isocyanates are an important cause of asthma and occupational type exposures to atmospheric concentrations of 1 part per billion for usually brief periods of minutes suffice to elicit the various patterns of asthma. Workers have been sensitized to toluene di-isocyanate by indirect exposure through fumes from the exhaust of a neighbouring factory which were sucked into their ventilation system. This illustrates the hazardous potential of environmental exposure to these substances. The burning of polyurethane materials, abundant in domestic environment, liberates appreciable amounts of di-isocyanates. They are also commonly encountered in varnishes, adhesives, and spray paints used in or around the home.

Discussion:

Hollowell & Miksch (1981, p.6) note that the levels they found for individual organics (1-100 ppb range) were all well below existing limits established by OSHA for occupational exposure. They caution that such levels may be excessive for the general public for whom limits are typically 10 times lower. They note further that the present OSHA standards do not adequately address:

1) additive or synergistic effects of two or more chemicals
2) chronic exposure rather than acute exposure
3) the full diversity of the population
4) annoyance from odours

1.2.19 Summary Table

Section & Pollutant	Descriptive Summary
1.2.1 Carbon Monoxide	Major sources are gas stoves, fossil fuel furnaces and heaters. Exposure is widespread and often at levels above outdoor standards. Faulty furnaces have given rise to fatal carbon monoxide concentrations.
1.2.2 Radon	Radon and radon decay products are present in most homes and may present a measurable cancer risk from radiation. Concentrations are greater in energy-efficient homes with reduced ventilation.
1.2.3 Nitrogen Oxides	Tobacco smoking and indoor combustion appliances are the major sources, often at levels exceeding outdoor ambient standards. Increased incidence of illness has been correlated with elevated NO2 and other pollutant levels in homes with gas stoves.
1.2.4 Sulphur Dioxide	Indoor concentrations often lower than those outside due to adsorption on building surfaces. Fossil fuel combustion is primary indoor source.
1.2.5 Ozone	Improperly maintained electrostatic air filters can produce ozone at levels above outdoor ambient standards. Persons already hyper-reactive are at greatest risk.
1.2.6 Asbestos	Potential sources include many products no longer produced but still present in many homes. Fibers are carcinogenic.
1.2.7 Tobacco Smoke	Tobacco smoking is the major source of indoor respirable suspended particulates, producing concentrations well in excess of outdoor ambient standards. Contains known and potent carcinogens. Detrimental effects on the health of smokers and nonsmokers have been well documented.
1.2.8 Formaldehyde	Major sources include building materials and furnishings. Adverse health effects have been documented, even at levels below new indoor standards. Exposure can lead in some cases to widespread chemical susceptibility. Suspected carcinogen.
1.2.9 Carbon Dioxide	Indoor concentrations are often very much greater than outdoor concentrations. Unvented kerosene heaters can produce concentrations well in excess of occupational standards. Long-term health effects from these levels are not well researched but are a cause for concern.
1.2.10 House Dust	House dust contains a wide variety of compounds that can be allergenic and therefore may adversely affect the health of a significant proportion of the population. A reasonable degree of avoidance for affected persons is feasible.

1.2.19 Summary Table (continued)

1.2.11 Fungi (Mould)	Mould is universally present in homes but may grow significantly if there are sources of dampness. Moulds contain potent allergenic compounds and can adversely affect health. They can be controlled with proper construction methods and environmental conditions.
1.2.12 Bacteria/Virus	Bacteria may grow in warm standing water such as is found in some humidifiers. Health effects are potentially serious, but the incidence is not known and may be small. Transmission of infection by bacteria and virus increases with reduced ventilation.
1.2.13 Aerosols	Many consumer aerosol products yield high pollutant concentrations that could present serious health hazards. Persons with cardiovascular or pulmonary impairment are at greater risk.
1.2.14 Other Particles	Various household materials and activities in addition to smoking produce suspended particulates. Some particulates can cause irritation and lung disease. More research is needed particularly concerning possible carcinogens.
1.2.15 Pesticides	Pesticides are widely used indoors and measurable concentrations have been found in human blood and tissue. Numerous incidents of illness have been reported and pesticides are suspected to be potent sensitizers which can lead to a more widespread chemical susceptibility.
1.2.16 Ammonia	Ammonia is often present in indoor air in small quantities and is known to irritate those susceptible. Little data on incidence or health effects at low levels is available.
1.2.17 Chlorine	Chlorine compounds are present in the home particularly in laundry preparations and in municipal water. Chemically susceptible individuals are known to be adversely affected but no data is available on indoor concentrations or long term health effects.
1.2.18 Organic Vapours	Indoor air often contains complex mixes of organic vapours, each at low levels but in combination at levels exceeding outdoor and other standards. Little is known of the short and long-term health effects of many of the organic compounds mentioned, at the low levels of exposure that occur. Many compounds present have detrimental effects at high concentrations and are known to affect hypersusceptible persons at levels commonly found in homes.

1.3 THE PEOPLE AFFECTED

1.3.1 The General Population

Air pollutants appear to adversely affect people in a number of ways:

1) direct toxic and irritant effects
2) increased susceptibility to developing disease from other causes
3) aggravation of existing disease
4) sensitization to the same and other environmental agents
5) as part of our total 'stress' load

Direct toxic or irritant effects, that is, symptoms expected to arise in most people when exposed to specific concentrations of a pollutant, have been described in the previous section. In many cases the data has been derived from moderate to high industrial exposures. While this does indicate the relative danger of various pollutants it does not confirm whether there are direct toxic effects from many pollutants which are present only at lower exposures levels indoors.

Barnes (1975) emphasizes that there is no simple formula by which it is possible from knowledge about toxic doses to derive a lower level that, on repeated administration, will be innocuous. He predicts that as chemical and biochemical analyses become more sensitive it will become increasingly possible to detect changes produced by the presence of small quantities of toxic compounds. However, he cautions that it may often be very doubtful whether such changes represent a disadvantage to the exposed person.

For high level exposures such as carbon monoxide and nitrogen dioxide concentrations from faulty furnaces, unventilated stoves and heaters in tightly sealed houses, it can correctly be said that anyone in the general population who is thus exposed is at risk of developing direct toxic effects. Other agents such as formaldehyde have been shown to have characteristic irritant effects for the general population at the levels found in some homes (e.g. with Urea-formaldehyde Foam Insulation). Radon gas exposures are known to produce a certain number of cases of lung cancers in any exposed population. As more research is conducted into the long-term effects of low-level exposures, it is not only possible but likely that additional toxic and irritant effects related to indoor air pollutants are discovered.

Many of the studies dealing with lower levels of pollution exposure address effects other than direct toxic and irritant effects. They have demonstrated that at least a small proportion of the population can be expected to experience increased susceptibility to other disease, worsening of existing disease, or sensitization with or without other disease.
The persons affected have been categorized according to various 'risk-groups', for example, by age or by disease.

Hammer et al (1974) report that in a comparison of three high-air-pollution areas with one lower-pollution area in New York City in 1972, rates of lower respiratory disease (croup, bronchitis, and other chest infections) in children were significantly higher in the high-pollution areas. They noted that differences in family size and composition, crowding, parental cigarette smoking, or indoor air pollution due to gas stoves or gas space heaters could not explain the excess of disease in the high exposure communities. Their best judgment estimate of the average annual pollutant concentrations associated with excess childhood respiratory disease was 175 to 250 mcg/m^3 of SO2, 85 to 110 mcg/m^3 of total suspended particulates, and about 13 to 14 mcg/m^3 of suspended sulphates.

Studies on the incidence of respiratory problems in children exposed indoors to the pollutants emitted by gas stoves (discussed in section 1.2 under "Nitrogen Dioxide") yield similar results. Preliminary data on persons exposed to Urea-Formaldehyde Foam Insulation indicates that there may be an immuno-suppressive effect to such exposures (Sprague, 1982). Preliminary studies of UFF-exposed people in Canada have yielded similar conclusions. Dr. Albert Nantel of the Centre de Toxicologie du Quebec, Laval University, Quebec, testified before a Hazardous Products Act Review Board Hearing in December 1981, suggesting that for some people exposure to UFFI gases may produce a severe depression in the natural defence mechanism. He stated that that in such cases where people's immunological defence processes are inactivated, they may become easy prey for various 'exogenous and endogenous aggressors', including bacteria, viruses, allergens, fungi and chemical agents.

This pattern can be expected to continue as more research is undertaken. Green (1974, p. 163) emphasizes that the lung chronically exposed to air pollutants is an abnormal lung in respect to its complement of defense mechanisms. He speculates that the suppressive effect of air pollutant exposure on the immune response in the lung may contribute not only to the increased susceptibility to bacterial infection in the lung but may impair the development of effective immunity to viral infection as well.

Severs (1980, p. 123) notes that retrospective and prospective epidemiological studies have played the major role in demonstrating that air pollution can cause morbidity and mortality in stressed individuals. Major episodes contributing to this conclusion include: London, England (1952, 1956), Meuse Valley, Belgium (1930), Donora, Pennsylvania (1948), and New York City (1963, 1966). This association of air pollution with mortality above an expected rate and the confirmation of cardiorespiratory distress in clinical patients as well as autopsy data contributed the first convincing evidence that air pollution had any effect on health.

Green (1974, p. 163) confirms that conditions such as asthma can be modified and worsened in individuals chronically exposed to air pollution. He notes that clinical experience, and epidemiological data, both hold that attacks of asthma in children and adults are associated with acute episodes of air pollution on the one hand, and with respiratory tract infections on the other. Other studies have been cited in Section 1.2, in relation to specific air pollutants, for example increased risk to cardiac patients under exposure to carbon monoxide.

Persons who have become sensitized to low-level exposures to various pollutants represent a special risk category. In some cases a mild sensitivity to one chemical gradually worsens and 'spreads' to other chemicals (Small, 1982a, p. 53). In the more severe stages such persons are chronically ill and experience debilitating episodes of acute illness even with minute chemical exposures, at and even far below the levels commonly encountered in indoor air. Pepys (1981) notes that the increasing use of chemical agents of many sorts in the home and elsewhere poses considerable problems in diagnosis and management of sensitized persons, because of the minuteness of the amounts needed to elicit reactions.

Some researchers have also presented clinical data to prove that some persons who have no history of health problems, and therefore do not belong to a particular 'risk group', have been adversely affected. This raises the question as to how many formerly healthy people are now in 'high-risk' category because of the direct effects of pollution rather than because of independent causes of disease.

For example, in Finkel and Duel (1974, p. 185), R. E. Smith concludes that exposure to air pollution can not only cause specific allergic disease but can lower the threshold for other allergies and thus increase the incidence of allergic disease in an exposed population. He also notes that it can harm the immunologic barrier to infectious diseases caused by viruses, bacteria and possibly granulomas and fungal diseases. He suggests as a sound clinical goal the minimizing of total life-long exposures to antigens or to organic and inorganic particles. Pepys (1981) states that the findings in occupational asthma show that industrialization in itself and its influence on the home could be partly related to the more common diagnosis of asthma. He notes at the same time that an understanding of the nature of the relevant allergic mechanisms is needed.

Evidence indicating that exposure to a particular indoor pollutant or mix of pollutants can induce a state of general chemical susceptibility has been put forth in connection with exposure to gases from Urea-formaldehyde Foam Insulation and particleboard (Small, 1982a, p 60). The role of other exposures in bringing about this state will be discussed further below.

In addition it must be recognized that the distinction between the 'healthy' people and those supposedly at higher risk when exposed to air pollution is an illusory one. Calabrese (1978, p. 193-197) points out that susceptibility to pollution varies widely for any one individual over time. When high-risk periods during everyone's lifetime are taken into account (when very young and very old, during fetal development, in adolescence, and during episodes of temporary illness), this includes the entire population. In addition, each individual has daily weak points or times of greatest sensitivity to the toxic effects of pollutants. Normal circadian rhythms and disruptions in them caused by jet lag or shift work are also suspected to cause periods of increased susceptibility.

The California Department of Consumer Affairs (1982, p. ES3) commented that during preparation of their overview study, the authors encountered the common assertion that people especially sensitive to indoor pollution are "different". They were often referred to as "canaries", by analogy with canaries used in mineshafts to detect the presence of gases. However, of those reporting environmental sensitivity to low concentrations of pollutants on a study questionnaire, almost half reported themselves to have been healthy and without special sensitivities or complex allergies up to a certain time, i.e. totally indistinguishable from the 'non-canaries'. Then an illness (usually mononucleosis or "viral" hepatitis) or chemical exposure rendered them highly sensitive to many environmental factors. Previously productive, happy people reported themselves to be "so sensitive to the modern world that we cannot adapt or live unencumbered".

The following subsections deal more specifically with high-risk groups. The first deals with persons who are known to be at higher than normal risk to adverse effects of pollutants because of age or specific disease. The second describes chemical susceptibility, a condition in which people are adversely affected more directly, usually from even relatively small exposures to a wide variety of common pollutants both indoor and out.

1.3.2 **Specific High-Risk Groups**

Cooper (1973) stresses that it is accepted in occupational medicine that individuals differ widely in their susceptibility to toxic agents and other environmental stresses. Some individuals show effects at concentrations which do not affect the majority, while at the other end of the dose-response curve there are individuals who are unusually resistant.

Calabrese (1980) notes that it has been recognized that there is a differential susceptibility of humans to environmental carcinogens and toxicants, and that it has been the subject of a United States Environmental Protection Agency conference (Conference on the Increased Human Susceptibility to Environmental and Occupational Pollutants, University of Massachusetts, Amherst, Massachusetts, June 1978).

Calabrese (1978b) defines 'high-risk groups' as those individuals who experience toxic and/or carcinogenic effects significantly before the general population as a result of one or more biologic factors, including developmental influences, genetic factors, nutritional inadequacies, disease conditions, and behavioural or life style characteristics. Calabrese suggests that identification of such high-risk groups is important in setting standards:

> "Knowing which individuals are at high risk with respect to pollutants is very important, because these are the people who will be the first to experience morbidity and mortality as pollutant levels increase. If the high-risk segments are protected, the entire population is protected. Consequently, information concerning both the identification and quantification of high-risk groups should play an integral role in the derivation of standards for pollutants in both ambient and industrial air as well as in drinking water." (Calabrese, 1978b, p. 56)

Calabrese (1978a and 1978b) emphasizes that it is an illusion to assume that a threshold for chemical exposure exists in the highly diverse human population. Nor can it be assumed that separate thresholds exist for so-called normal people and for high-risk groups. Each high-risk group has multiple variations and ultimately, each individual has a unique threshold.

Specific high risk groups include people with easily identifiable risk characteristics, e.g. the very young, the very old, pregnant women, people with respiratory ailments or cardiovascular disease, people with certain genetic backgrounds, dietary habits or nutritional deficiencies, people who consume large amounts of alcohol or drugs, people who smoke, and various others.

Calabrese (1978, p. 187) identified a number of high-risk groups along with the pollutant class to which they are or may be hypersusceptible. The terms used are general. Readers are referred to the cited work for a more specific list of functional disorders and further literature references.

High-Risk Category	Pollutant Class
immature immune system	respiratory irritants
deficient immune system as a function of age	respiratory irritants carcinogens
circadian rhythms including phase shifts (jet lag, shift work)	hydrocarbon carcinogens and probably most other pollutants
cystic fibrosis	respiratory irritants
immunoglobulin A deficiency	respiratory irritants
immunologic hypersensitivity	isocyanates
serum alpha$_1$ antitrypsin	respiratory irritants
vitamin A deficiency	hydrocarbon carcinogens
iron deficiency	hydrocarbon carcinogens
riboflavin deficiency	hydrocarbon carcinogens
asthmatic disease	respiratory irritants
chronic respiratory disease	respiratory irritants
heart disease	respiratory irritants
smoking	hydrocarbons
drug taking	numerous potential substances

Size of the High-Risk Population

Calabrese (1978, p. 193-197) makes the point that it is erroneously assumed that high-risk groups represent only a small number of people. In fact, taken together, they represent a large proportion of the population. In the U.S. population he cites a total of 25-35 million people who would be at higher risk in exposure to a number of pollutants because of chronic respiratory disease and heart disease alone. Figures in Canada are likely similar but require confirmation. The total of identifiable high-risk groups because of existing disease exceeds 20% of the population. When age, smoking and nutrition are taken into account the figure is greater than one third.

There is considerable evidence that persons with cardiovascular and respiratory diseases may be at increased risk from exposure to pollutants in general. Carnow and Carnow (1974, pp. 127-156) indicate that aggravation of symptoms in such people appears to occur at lower levels than local ambient air quality standards.

Persons who are already living in relatively polluted surroundings may also represent a high-risk group under continued or increased exposure. Fairbairn and Reid (1958) demonstrated a relation between higher pollutant levels and generally lower levels of pulmonary function, in city populations exposed to high pollution compared with those exposed to lower pollution levels. Calabrese (1978a) has also identified smokers as being at greater risk from the adverse effects of other pollutants.

Brundrett (1979, p.4) states that the proportion of the population that is susceptible to "humidifier fever" (see section 1.2 under "Bacteria") appears to depend on the contamination level. If it is sufficiently high then all the occupants will experience the symptoms. He notes that there does not appear to be an age factor but that there may be a higher susceptibility for allergic individuals. He reports that in a 1977 outbreak researchers found that half of the people who experienced difficulty were also sensitive to common allergens as shown by a skin test.

Calabrese (1978, p. 171) notes that in the U.S. high-risk segments of the population were not specifically considered in the standard-setting process because there was not sufficient information about them to provide any quantitative assessment of risk, and because it was assumed that they composed only a small segment of the population. Despite the fact that safety factors recognize that certain people are more sensitive to pollutants than others, they are inherently imprecise. He states:

> "The identification and quantification of individuals at high risk to environmental or occupational pollutants is of profound significance for the determination of public policy with respect to the well-being of our economy and our personal health. Specifically, it provides a reasonable characterization of the type and number of people who would first experience morbidity and possibly death at particular levels of pollutant exposure. Such a characterization provides practical applications to deal with the numerous occupational and environmental health problems effectively."

1.3.3 General Chemical Susceptibility

Reinhardt (1978) defines the term 'hypersusceptibility' as a state of being readily affected or acted upon. He notes that in occupational medicine, researchers have been concerned with workers who react to certain substances at low levels, below the threshold concentration associated with injury or definite discomfort in others.

Rea, Suits et al (1980) studied patients in a specially constructed Environmental Unit designed to reduce chemical exposures to an absolute minimum. Patients were re-exposed to common chemicals in low concentrations under controlled conditions after a separation period in the unit. They found that reactions could be triggered in some patients by exposure to minute amounts of outgassing chemicals or particles contained in many building materials.

Randolph (1962) describes this chronic illness as resulting from "maladaptation" to many common chemical exposures in our environment. He notes that at first this may show as irritation of the eyes, nose, lips and skin, bronchitis, and mild gastrointestinal symptoms. The condition may progress to include more severe and chronic respiratory symptoms, sinus involvement, bronchial asthma, and a wide range of more troublesome gastrointestinal problems.

A general tiredness or cut-back in former energy, lack of initiative, forgetfulness, and difficulty concentrating are reported to accompany the more specific symptoms mentioned above. Various other symptoms including headache, myalgia, fibrositis, arthralgia and arthritis, neuritis, edema, palpitation, excessive perspiration, pallor and weakness may also be present. Some cases progress to advanced psychiatric disturbances, with or without persistence of chronic physical symptoms.

The condition is confirmed in the manner described above by Rea, involving separation from environmental exposures. On separation from exposures which are suspected of causing the illness, the chemically susceptible person may first experience withdrawal or 'hangover- like' symptoms, after which he or she may become relatively symptom-free under continued environmental control. Subsequent test exposures to common chemicals often bring on acute and immediate reactions similar to but often in greater intensity than previous chronic symptoms. Subsequent avoidance of exposure to chemicals which provoked strong responses under the test conditions has proven beneficial.

The California Department of Consumer Affairs (1982, p. II.F.4) describes as well the phenomenon of 'adaptation', whereby there may be temporarily a lack of noticeable effects from an environmental stressor, yet at a biochemical level the toxicity may still progress. 'Adaptation' can be 'unmasked' by separation from the suspected chemical exposures, followed by reexposure.

Although occasionally such people may be susceptible and maladapted to a single substance, responses to a number of different materials is the norm. This can include allergic or allergic-like responses to common allergens including inhalants and foods.

Rea, Bell et al (1978) report that once an individual is sensitized to a solitary chemical, continued exposures result in a spreading phenomenon. Once this spreading occurs, reactions then proceed upon minute exposures. Some persons studied had received a massive exposure to one type of chemical, and subsequently became intolerant to ambient concentrations of many others. No mechanism has yet been comfirmed for this spreading phenomenon.

The medical literature indicates some controversy over the mechanism for such environmental reactions, as to whether the chemicals involved act as toxins, irritants, or allergens. Although many of the symptoms resemble allergy or allergic-like reactions, it has been noted that many of the reactions observed do not manifest antibody formation and therefore do not fit into the immunological definition of allergy (Philpott, 1980, p. 7). Calabrese (1980) notes that differences in nutritional status provide at least a partial explanation for the wide variations in human susceptibility to chemical exposures. Shakman (1974), for example, cites experiments on rats which showed that nutritional influences increased the toxicity of most pesticides.

In describing the phenomenon of chemical susceptibility, Rea, Bell et al (1978, p. 101) postulate a 'total load' concept. Each individual seems to possess a limited capacity to handle the total load of environmental pollutants and other stresses. If a person is chemically susceptible, the total load he or she can handle is markedly reduced from that of others.

For persons who are already chemically susceptible, high levels of indoor air pollution represent considerable risks. Rea reports that follow-up studies in patients with multiple sensitizations showed an extremely slow recovery time that seemed to be dependent on maintaining as low as possible total chemical overexposures for the patient. Those patients who were not able to maintain strict avoidance of the substances that affected their health rapidly deteriorated.

For the chemically susceptible person, household chemicals apparently tolerated by most of the population may provoke a wide variety of symptoms, similar to those in the following example (Rea, Bell et al, 1978):

> "This 41-year-old white female had been living comfortably in her home for the previous four years. She experienced symptoms of excess salivation, tremors, diarrhea, nausea, swollen hands, slight fever, fatigue, sore throat, and coughing within 24 hours of exposure to heptachlor after pesticide treatment of her home. These symptoms have continued for approximately one year with lessening of the tremors, diarrhea, and fever. Since the

../ continued

overexposure this woman has been unable to tolerate common chemicals found in the ordinary living situation. Examples are:

(1) Gas utilities (hot water and heat) produce symptoms of facial flushing and impaired intellectual functioning. Continued exposure results in nausea and vomiting.
(2) Vapors resulting from filling a bathtub with city water cause coughing and sore throat. This gets worse if she gets in the tub.
(3) Contact with permanent pressed or synthetic fabrics results in itching on the back and shoulders.
(4) Pesticide inhalation produces headache and malaise.
(5) The patient is no longer able to wear perfume or tolerate the odor on others. Headache results.
(6) Dye in fabric or clothing produces nasal tightness.
(7) Vinyl wallpaper causes vice-like pressure headache.
(8) Alcoholic beverages cause nasal burning and nausea.
(9) The patient's reading speed is greatly decreased.
(10)Loss of tolerance to some formerly non-reactive foods has also occurred.

The same researchers reported on a study of a series of twelve patients with cardiac arrhythmias and/or chest pains, in carefully controlled low-pollution environmental conditions. Double-blind test challenges were performed with ambient doses of commonly encountered household chemicals, including: formaldehyde, phenol, petroleum alcohol, pesticide mixture, and pine-scented floor wash.

Ten out of the twelve patients demonstrated positive reactions to at least four out of these six exposures. Response included cardiac arrhythmias as well as various other symptoms including rhinorrhea, nasal stuffiness, hoarseness, cough, wheezing, peripheral blanching, cyanosis, nausea, vomiting, swelling or loss of pulses, bruising, polyuria, fever, increased pulse rate, blood pressure decreased or elevated, petechiae, bruising and phlebitis. Seven out of twelve patients in the series showed response to formaldehyde exposure. Subsequent changes in patients' homes to lower the previous high total load of chemicals was associated with 'marked clinical improvement'.

Numerous building components have been shown to cause adverse reactions in susceptible persons, including various forms of insulation in addition to UFF insulation, fire retardant-treated cellulose, plastic vapour-barrier material, wood preservatives, fungicide-treated wallboard, various paints, urethanes and other sealers, coatings on electric wiring, gas and oil supply lines, soft flooring materials, various types of caulking, putty and other sealants, vinyl window components, particularly when exposed to sunlight, and almost all forms of adhesives (Small, 1978, 1979a,b).

Randolph (1962, p. 19) describes the following home chemical exposures as having been responsible for illness:

- exposure to utility gas or the combustion products of gas, oil or coal - the most troublesome being exhausts from fuel-oil or gas ranges or room heaters, gas refrigerators, gas water heaters and gas driers;
- coal smoke
- warm air heating system odours, irrespective of fuel employed
- odours of oil-impregnated filters of air conditioning equipment and evaporating oil from certain other equipment such as motors in electric fans and heaters
- odours of fresh paint, turpentine, mineral spirits, synthetic alcohol, detergents, household deodorants, disinfectants, Chlorox, ammonia, adhesive cements, sponge rubber bedding and padding
- certain odourous plastics, including upholstery
- insecticide sprays, napthalein, dichlorobenzene and certain other insect repellants.

Zamm (1980, p. 51) concludes that most of the offending vapours within the average home (if no one smokes) comes from evaporation. He notes that there are numerous household products and building materials that expel vapours for weeks, months and years. His general rule of thumb: "If you can't eat it, don't breathe it".

Recent evidence suggests that cumulative low-level chemical exposures may be responsible for a general immune suppression effect underlying general chemical susceptibility. Rea (1978) demonstrated that T-cell depression occurs in some chemically susceptible patients and returns to higher levels when these patients are kept away from chemical exposures. Significant changes were seen in various laboratory parameters following challenge with chemical exposures, including decreases in eosinophil count, total complement, IgG levels, C^3, and T lymphocytes.

This author's experience with individuals sensitized to indoor chemical exposures indicates that there is an identifiable Canadian population of chemically susceptible persons, numbering in the thousands and growing quickly as awareness of the problem has increased. Limited surveys have shown that there is a limited but definite demand for low-pollution housing for chemically susceptible and other allergic persons, in or near Canada's major urban centres (Lipinski, 1979). This population has had considerable difficulty locating existing housing with indoor pollution levels low enough to be of any therapeutic benefit, and in some cases low enough even to be tolerable.

1.3.3 The People Affected: General Chemical Susceptibility (continued)

To date, however, there is no reliable evidence which would indicate how many people within the Canadian population are generally chemically susceptible to the point that household indoor air pollution exposures could elicit symptoms (Small, 1982a). Some physicians have estimated that the size of this population is likely to be on the order of the number of people with known inhalant allergies (15-20%) or greater. Olishefski (1981), for example, has stated that persons prone to allergies are more susceptible to allergenic chemical sensitizers. To this author's knowledge, however, no studies have been undertaken to confirm this.

A more detailed treatment of chemical susceptibility with special reference to indoor formaldehyde exposures is given in a previous publication by this author (Small, 1982a). The roles played by chemical susceptibility and polluted indoor air in reducing safety and causing accidents indoors is also outlined in a further publication (Small, 1982b).

1.4 MEDICAL UNKNOWNS

That the general population is exposed to indoor air pollution is not in doubt. One U.S. study states that on the average, employed Americans spend 90% of the day indoors, and that homemakers and retired people spend up to 95% of their day indoors (National Research Council, U.S., 1981, p. II-8). No Canadian data was found, but it is likely that Canadian percentages will be comparable or greater due to the generally cooler climate.

Neither is there doubt that many of the chemicals that are present in indoor air can be highly toxic in sufficient concentrations. It is also well accepted that at least some of the indoor exposures described in Section 1.2 of this report can be dangerous to health.

However, the literature on indoor air pollution is permeated with one over-riding theme: there is not yet enough information to know for sure the full extent of health damage from indoor air pollution. All that is certain is that with the present awareness of a growing problem, research should now be focussed on finding the answers.

Two primary problems make it difficult to interpret the results presented in the preceding sections:

> 1) Most of the pollution standards in this country and others have been based on industrial or outdoor factors. Neither outdoor nor industrial exposures are similar to the long-term, continuous, low-level exposure that many people experience at home indoors.
>
> 2) Most of the pollution criteria are based on studies of single-chemical exposures, and very little is known about the synergistic effects of complex mixes of air contaminants. Calabrese (1978b, pp. 76-87) lists numerous examples of synergistic chemical interactions (in which the effect resulting from exposure to a mix of chemicals is greater than the sum of the effects resulting from exposure to each chemical individually).

A great deal more data is needed before the problem can be properly understood in any reasonable perspective. The list of unknowns below demonstrates that Canada is dealing with a problem that requires literally decades of good research. Cutbacks in environmental research in countries like the United States, on which Canada relies heavily for technical information, have also made it even more necessary to encourage such work here. If the long-term task is to be accomplished, the type of data must be decided and collection must begin soon. The kind of information that is missing is as follows:

a) the detailed characteristics and degree of indoor air pollution in housing across Canada

b) the detailed characteristics and degree of individual air pollution exposures that Canadians are subject to (two individuals in the same environment may receive different doses depending on activity, and everyone's total load may be different)

c) the number of Canadians who are presently adversely affected by indoor air pollution

d) the full range of possible health effects of long-term low-level exposure to these indoor air pollutants, individually and in mixes

e) the number of Canadians at high risk due to inherent susceptibility to pollution

f) the estimated number of people who could develop adverse symptoms over long-term exposure

g) ways to properly treat and rehabilitate those whose health has been impaired by excessive indoor air pollution

h) the present and projected future social costs attributable to the effects of indoor air pollution

i) the present and projected future impact on the health care system of health damage attributable to indoor air pollution

j) the nature of legal liability involved in situations where individuals have been adversely affected by building environments provided by others

As Section 1.2 also demonstrates, the problem of indoor air pollution and the people affected cannot wait the decades it will take to catch up scientifically with the effects of our present building and manufacturing technology. For this reason it is extremely important to begin immediately to co-ordinate the efforts of those who are studying the problem with those people who are in positions of responsibility who may begin to create the changes needed.

Individual Canadians also have a right to know what our information base on indoor air pollution is now, so that they can weigh the knowns and unknowns, and make their own personal decisions about the environment in which they wish to live. And the individuals who are already adversely affected urgently need knowledgeable medical attention and better environments.

Few researchers have attempted to estimate the medical and social costs stemming from indoor air pollution. Those who have made very broad assumptions. The California Department of Consumer Affairs (1982, p. ES1, ES1, I.1, and II.E.6) estimates that indoor pollution may be contributing anywhere from $15 billion to $100 billion annually to health care costs in the United States, based on an estimate that 5-30% of U.S. health care costs derive from indoor pollution-based risk factors.

The authors of California's review concluded that if current trends in new building products and technologies partially responsible for increased indoor air pollution levels continued unabated, that the building industry, the general U.S. economy, and the health of the general public could be severely disrupted. From the research presented in the previous section, this author can only conclude that the above statement applies equally to Canada.

1.5 POLLUTANT SOURCES (Cross-Index of Pollutants by Source)

The following sections include additional information and research material that is more oriented to the particular pollution source than to individual pollutants. They represent specific problem areas with Canadian homes that can be addressed in further research.

Sub-Index of Pollutant Source Summaries

		page
1.5.1	Improper Chimney Construction for Gas Furnaces	102
1.5.2	Gas Stoves	103
1.5.3	Unvented Gas and Kerosene Heaters	106
1.5.4	Fossil Fuel Furnaces	108
1.5.5	Wood and Coal Furnaces or Stoves	109
1.5.6	Outgassing of Furnishings and Decorative Materials	110
1.5.7	Intrusion of Outdoor Pollutants	113
1.5.8	Use of Household Chemicals	115
1.5.9	Consumer Appliances	117
1.5.10	Spray Humidifiers	119
1.5.11	Paints and Sealers	120
1.5.12	Insulation	124
1.5.13	Occupants' Activities	126
1.5.14	Summary Table	127

1.5.1 Improper Chimney Construction for Gas Furnaces

Description:

Since 1980, approximately 100,000 people across Canada have converted home furnaces to natural gas under a federal government incentives program. The Ontario Ministry of Consumer and Commercial Relations has warned that some installations did not include chimney liners which are required for natural gas operation.

Pollutants Produced:

Exhausts from natural gas furnaces can corrode brick and mortar in unlined chimneys, and can lead to falling pieces and clogging of the chimney. Poisonous exhaust gases, and in particular, carbon monoxide, are restricted from rising up the chimney and accumulate instead in the home.

Discussion:

Recent media reports note that there are eight deaths in the Ontario coroner's records which have occurred since 1979, as a result of carbon monoxide poisoning from clogged chimneys.

A federal subsidy program is now in place through the Department of Energy, Mines and Resources to assist homeowners who have not already installed liners in doing so.

In a 1980 inquest in St. Catharines into the death of three persons in this manner, the coroner suggested that there should be legislation making it mandatory to have chimneys swept and inspected regularly.

Many of the liners now being installed are stainless steel. Questions have been raised concerning the suitability of an aluminum/galvanized steel liner which is also being installed. The Ontario Chimney Sweeps Association has claimed that such liners corrode quickly and will not prevent the deterioration of the chimney over the long run (Toronto Star, August 28, 1982).

1.5.2 Gas Stoves

Description:

Kitchen cooking devices, fueled by natural gas. Usually has oven and up to four burners, and pilot light.

Pollutants Produced:

Carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO) and respirable particulates (Hollowell, 1981, p. 4,5).

Emission Rates:

Cote, Wade & Yocom (1974) measured carbon monoxide emission rates of gas stoves as follows (as reported in Brookman and Birenzvige, 1980, p. 6):

	older stove with cast iron burners		newer stove with pressed steel burners	
	mcg/kcal	mg/hr	mcg/kcal	mg/hr
with pilot light only	419	62.9	842	84.2
1 burner - high flame	382	1031	510	1785
3 burners - high flame	475	3220	315	3213
oven at steady state	530	1166	1620	3564

Figure 7 opposite illustrates how the carbon monoxide concentrations in one home varied with the use of a gas stove.

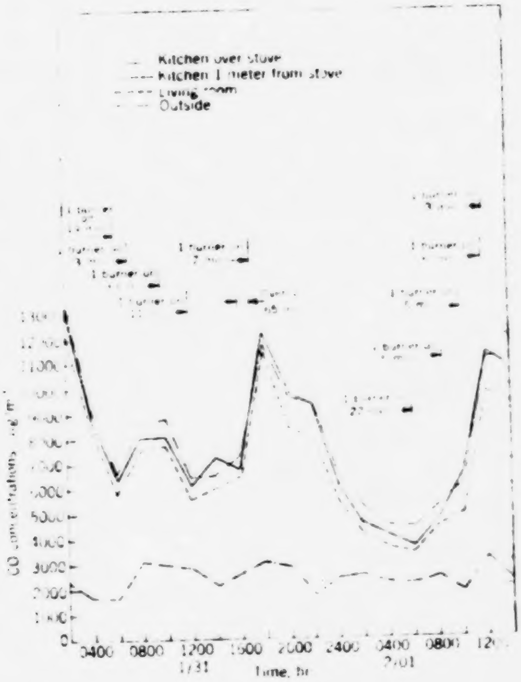


Figure 7: A Time History of CO Concentrations, 2 Hr. Averages, One House (from Wade, Cote and Yocom, 1975, p. 939)

Traynor et al (1981b, p. 9) calculated emission rates for a gas stove from a theoretical model combined with pollutant concentrations produced in a special environmental chamber:

Gases	Gas oven operated at 180 degrees C (350 F)	One top burner on high with water-filled pot
CO	950 mcg/kcal.	840 mcg/kcal.
CO2	182,000	191,000
NOx (as N)	26	36
SO2	0.46	0.68
particles (lt .5 microns)	.061	2.1

Heat output for the stove used was 2000 kcal/hr for the oven at steady state at 180 deg. C, and 2200 kcal/hr/burner on high.

Hollowell and Traynor (1978, p.5) also report that particulate air samples collected in residential buildings showed an increase in indoor particulate sulphur during periods of gas stove use. The indoor particulate levels for other species (Pb, Zn, Fe, and Ca) were comparable to or lower than the outdoor levels during all periods. An average emission rate of particulate sulphur from gas stoves was measured to be 0.02 mcg/kcal. The increase in sulphate in a typical kitchen is calculated and observed to be approximately 2 mcg/m^3 after operating a gas oven for hour.

Hollowell and Traynor (1978, p.6) note that emission rates vary considerably from one stove to another, and that there is considerable variation in a single stove if there is a change in any of the operating conditions such as the primary air supply.

Discussion:

Zamm (1980, p. 23) notes from clinical experience that a great many women have become chemically sensitive to the fumes from gas stoves, and when the gas range is replaced with an electric one, the depression that is common among them often disappears.

Brookman & Birenzvige (1980, p.5) reported that the emission rate of carbon monoxide increases as the oxygen supply decreases, e.g. by operating more than one burner and/or by placing a utensil on the burner. Sterling and Sterling (1979) also note that increases in carbon monoxide caused by covering the burners with cooking pans may be accompanied by a large variety of other pollutants produced because of incomplete combustion. Tanaka et al (1971) showed that in airtight buildings where the ventilation rate is low, the rate of CO production after prolonged operation of gas stoves and ovens can increase substantially, as the building oxygen level declines from a normal 21% to 20% or lower (as reported in Brooman & Birenzvige, 1980, p.5).

Hollowell and Traynor (1978, p. 9) conclude that elevated levels of gaseous air pollutants (CO, NO, and NO2) and particulate sulphur and nitrogen compounds are present in indoor environments when gas appliances are in use, and that their concentrations are extremely high when the air exchange rate is controlled to less than one air change per hour. Observed levels of CO and NO2 approach or exceed promulgated and proposed ambient air quality standards.

Silberstein (1979b, p. 188) recommends that if building envelopes are to be tightened, pilot lights should be eliminated and effective kitchen ventilation systems installed. He postulates a mathematical model which predicts that in a controlled ventilation chamber used by Hollowell, Budnitz and Traynor (1976) with 1/4 air change per hour, carbon monoxide peak levels of approximately 80 mcg/m^3 after a gas oven is on for 1 hour would take 4 1/2 hours to decline to the US EPA one-hour standard of 40 mcg/m^3. In his model higher air change rates do not significantly lower the peak concentrations, but do significantly decrease the duration of the high pollution levels.

1.5.3 Unvented Gas and Kerosene Heaters

Description:

Portable unvented kerosene-fired heaters are becoming very popular in both Canada and the United States as supplemental heating sources.

Pollutants Produced:

Carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO) and respirable particulates (Hollowell, 1981, p. 4,5).

Emission Rates:

Traynor et al (1982, p. 7) evaluated pollutant emission rates for unvented convective and radiant-type kerosene space heaters tested in a 27 m^3 environmental chamber with a ventilation rate of .4 changes per hour:

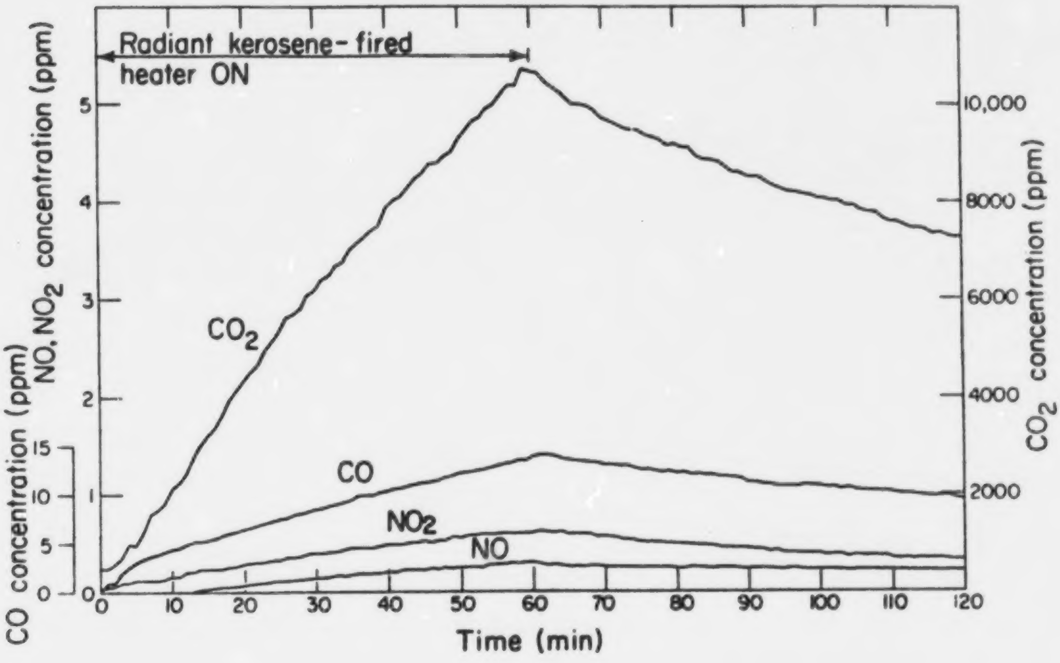
	New Convective Heater	New Radiant Heater
Fuel consumption	7830-7980 kJ/hr	8180 kJ/hr
Emission rates (mcg/kJ):		
CO	10.3-14.5 mcg/kJ	60.2 mcg/kJ
CO2	70,100-72,500	70,300
NOx (as N)	15.3-15.6	2.2
HCHO	0.01-0.08	0.63
O2	(-77,200)-(-78,900)	(-76,700)
fine particles	lt .004	lt .004
NO2/NOx volume ratio	0.25-0.28	0.67

Emission rates for carbon monoxide increased by a factor of 8 when the wick on the convective-type heater was reduced until the flame was approximately one-half its original length. Formaldehyde (HCHO) emission increased by a factor of 4, but there was no effect on fine particle emissions.

Figure 8 on the following page illustrates the CO, CO2, NO, and NO2 concentrations during operation of a portable, radiant-type kerosene-fired space heater in a well mixed 27 m^3 chamber. Fuel consumption was 8180 kJ/hr. (7760 Btu/hr) and the air exchange rate was 0.40 air changes per hour (Traynor et al, 1982, p. 9).

Lipmann (1979, p. 45) reports that NO2 levels in homes and trailers with unvented space heaters in the Gainesville, Florida, area were several times higher than those produced by gas stoves in the same or similar dwellings.

Figure 8: Pollutant Concentrations from a Portable Kerosene Heater in a 27 m^3 Test Chamber at 0.40 Air Changes per Hour (from Traynor et al, 1982, p. 9)



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Discussion:

In a recent review, Consumers Union (1982, p. 506,507) recommended that high-risk groups including asthmatics, people with chronic bronchitis, and people with allergies should avoid any continuous exposure to kerosene heaters. It cautioned that there might not be immediate hazards for others but that long-term effects could be harmful, and noted that electric heaters provide an effective and safe alternative.

1.5.4 Fossil Fuel Furnaces

Description:

Natural gas or oil furnaces.

Pollutants Produced:

Carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO) and respirable particulates (Hollowell, 1981, p. 4,5).

Fossil fuel furnaces installed properly and maintained regularly should not in theory pollute the indoor air. In actual fact, however, small cracks in heat exchangers, problematic chimneys with slow-generating drafts, and combustion chambers which leak fumes into furnace rooms particularly on initial firing of the furnace can contribute to indoor air pollution.

Discussion:

Silberstein (1979c, p. 271) notes that heating systems operate and pollute most at night, when it is coldest outside and when the greatest number of people are at home. He postulates a mathematical representation of pollutant concentrations that predicts an increase in heating system pollution three-fold for a four-fold reduction of infiltration, with no other factors changed. However, simultaneous reduction of conduction heat loss by addition of insulation can lower the heating demand sufficiently to keep the generation of pollutants from the heating system at the same level as before tightening a home. Silberstein notes, however, that retention of pollution from other sources besides the heating system could present a serious problem.

Very little work has been noted in the literature as to the amount of indoor air pollution that can be attributed to furnaces, although clinical experience has made it clear that a number of people have experienced illness from fossil fuel furnaces, that is ameliorated by replacement of gas or oil by electric heating. Persons who are known to have widespread chemical susceptibilities are more at risk than others.

1.5.5 Wood and Coal Furnaces or Stoves

Description:

The trend to greater use of wood stoves in Canada in order to use cheaper more available wood stocks instead of oil or gas has introduced a new source of pollution in many homes.

Pollutants Produced:

Moschandreas et al (1980) monitored indoor and outdoor pollutants for ten residences and two office buildings. Three of the residences used either a woodstove or a fireplace. Indoor total suspended particulate (TSP) concentrations during woodburning were about three times corresponding levels during non-woodburning periods. Elevated indoor concentrations of TSP, respirable suspended particulates, and benzo-a-pyrene were attributed to woodburning.

More than a hundred different chemicals have been identified in wood smoke, including carbon monoxide in quantities about 300 times that produced by an oil furnace. Hydrocarbon output may be about 700 times that of oil. Sulphur dioxide, however, is only about 10% of that produced by oil-burning. A number of the compounds in wood smoke are known carcinogens (e.g. benzo(a)pyrene) (Mohr, 1982).

Discussion:

A recent popular review (Mohr, 1982) has summarized the wood-burning problem as two-fold, involving both pollutants produced and retained indoors, and the introduction of significant concentrations of smoke from neighbouring chimneys. By comparison with oil or gas, wood is 'dirty' fuel. In the Portland, Oregon area, residential wood burning was estimated to contribute more respirable particulates to the outdoor air than all other sources combined. Several U.S. communities now require residents to restrict wood-burning during pollution alerts, and the Greater Vancouver Regional District has enacted a bylaw against excessive smoke from domestic heating installations. Great Britain and West Germany have some controls on the operation of wood-burning stoves in critical areas.

As with faulty operation of gas and oil furnaces, improper installation or operation of wood and coal stoves can lead to extremely high concentrations of carbon monoxide and potentially fatal conditions. Even with 'normal' operation some homes may have significant indoor pollution levels from operation of wood stoves. More data is needed to quantify the extent of this problem in Canada.

It is this author's experience that 'second-hand' wood smoke from neighbouring chimneys can be a considerable health hazard to persons who are already chemically susceptible. Persons badly affected by indoor chemicals can take steps to improve their own homes and avoid combustion indoors, but they are relatively defenseless against high levels of pollution in outdoor air.

1.5.6 Outgassing of Furnishings and Decorative Materials

Description:

Organic materials such as adhesives, elastomers, plastics, rubber, surface coatings and solvents produce contaminants by outgassing or evaporation, often for extended periods. Contaminants can also form from chemical or physical reactions when such materials are placed under thermal and oxidative stress. (Williams and Carhart, 1975, p.1)

A large number of polymer compounds are susceptible to slow chemical degradation at normal indoor temperatures, from a number of factors including temperature variations, humidity, light flux and wavelength, concentrations of reactive gases such as O_2, SO_2, NO_2, and O_3, and presence of small amounts of monomer and various additives and impurities within the product. Polyvinyl chloride, for example, is degraded in the presence of oxygen, producing HCl by a complex process. Other compounds may emit small molecules such as CO, CO_2, H_2O, H_2O_2, and small organic molecules such as carboxylic acids and ketones (Allara, 1975, p. 29).

Carpets, fibers and fabrics are also a source of various organic air contaminants (Finkel et al, 1979, 2).

Barker (1975, p. 44) stresses that it can be assumed that all fibers and fabrics contain measurable amounts of contaminants and additives. Natural fibers contain primarily contaminants of biological origin unless they have been treated with species such as arsenic for defoliation purposes. Man-made fibers may contain a wide variety of heavy metals, titanium dioxide, antistatic agents and flame retardants, and residues from polymerization and spinning processes. Textile fabrics may contain much larger quantities of added chemical material, particularly nitrogenous resins added to cellulose and cellulose blend fabrics to provide durable press properties. Significant levels of added chemicals may also be encountered in fabrics treated for flame resistance, soil release, oil and water repellancy, or other special purpose.

Barker reports that it is not uncommon for nitrogen-containing resins (e.g. urea-formaldehyde, dimethylol dihydroxyethyleneurea) to be present in quantities approaching 15-20% of the weight of the finished fabric. The materials are polymerized on the fabric, but hydrolysis products such as ammonia and formaldehyde can diffuse out of the fibers and contact the skin or enter the air. Nylon and polyester fabrics may also contain trace amounts of: catalysts, catalyst deactivators, metals and metal salts, delustrants, antistatic agents, flame retardants, residual monomer or small oligomers, lubricants, sizing agents, bleaches, wetting agents, dyes, printing pigments, soil release agents, softeners, water and/or oil repellants, ultraviolet absorbers, bacteriostats and fungistats.

Cain (1979, p. 267) reported that odour modifier chemicals are often added to many home products in order to reduce the perceived odour of the product. Permanent-press fabrics generally contain modifiers in order to combat malodours that may result from resins used in treatment of the fabrics. Even latex foam pillows contain modifiers to hide the rubber odour of the product.

Silver (1976) also reported that in the mid-1970s some gypsum wallboard samples were determined by the U.S. EPA to obtain measurable amounts of Arocolors 1242, 1254, and 1260 (all polychlorinated biphenyls - PCBs). These were present in the paper covering layer and were assumed either to have been added for fire retardant purposes, or to have been present in recycled paper used to make the product. Silver also describes unpleasant tactile sensations (e.g. a burning feeling) experienced by chemically susceptible persons exposed to soft plastic furniture coverings and polyester fabrics.

Pollutants Produced:

In mass spectrometry studies of emissions from carpets, fibers and fabrics, Finkel et al (1979, p.2) identified methyl bromide, sulphur dioxide, traces of palmitic and stearoic oxide, and three halogenated compounds - dibromodichloroethanol, tetrabromoethanol, and tribromochloroethanol. All the gaseous products were observed at temperatures of 20 degrees C and increased in concentration at higher temperatures. The researchers speculate that the organic halides were not thermal decomposition products since they were observed at the low temperature as well as higher temperatures. The halogenated ethanols may have been hydrolysis products of flame retardants. The fatty acids may have come from esters used as spin finish agents during the manufacture of the fibers, and the sulphur dioxide may have resulted from an anti-oxidant formulation. They were unable to explain the presence of methyl bromide, which is normally used as a fumigant.

Methyl bromide is a potent fumigant gas, and is one of the most toxic of the common alkyl halides. It has a toxic effect on the central nervous system and can lead to death when exposures are high (8600 to 60000 ppm.) Nonfatal poisoning has resulted from exposure to concentrations between 100 and 500 ppm. It is also a skin irritant. Because the reported study involved identification and not quantification, the significance of the presence of methyl bromide in the samples cannot be determined without further studies (Finkel et al, 1979, p.3).

With gas/liquid chromotography-mass spectrometry studies, Zweideinger (1977, p. 4) identified 147 organic compounds present in the interior of relatively new automobiles, which were not present in the ambient air in the vicinity of the test, including vinyl chloride monomer, a suspected carcinogen which outgasses from polyvinyl chloride (PVC). While an automobile represents a confined interior with a high plastic to volume ratio, and a high temperature variation (e.g. under sunlight), similar materials are now present in residences and similar temperature conditions arise at least locally when incoming sunlight strikes plastic surfaces. While no conclusions can be drawn about the possible concentrations of such products in residences, it is reasonable to assume that their presence at least in trace amounts is likely.

Among the compounds identified in the automobile study, besides vinyl chloride, were aniline, biphenyl, 1,2 dibromoethane (tentative), dichlorobenzene (tentative), dimethylphenol isomers, isobutyl alcohol, maleic anhydride (tentative), naphthalene, and 1,1,1-trichloroethane, which have all been associated with carcinogenic or neoplastic effects. Benzene, carbon tetrachloride, chloroform and phenol were found in the automobile interiors as well as in the background, and are also listed as carcinogenic or neoplastic. The primary categories of compounds detected were (Zweidinger, 1977, p.iv,25):

halogenated compounds (e.g. dichlorobenzene isomer)
aldehydes and ketones (e.g. methoxybenzaldehyde, methyl ethyl ketone)
alchohols (e.g. 2-methyl-1-propanol, creosol)
ethers (e.g. dimethyl ether, diphenoxybenzene)
nitrogen compounds (e.g. aniline, toluene diisocyanate)
sulphur compounds (e.g. carbon disulphide, benzothiazole)
aromatic hydrocarbons (e.g. isopropylbenzene, dimethylnaphthalene)
other hydrocarbons (e.g. n-butane, trimethylclyclohexane)

Hollowell & Traynor (1978, p.2) list vinyl chloride, organics, and odours.

Discussion:

Persons who have become generally susceptible to low levels of pollutant exposures have been reported to be sensitive to various furnishings and decorative materials. Avoidance of the sources is the primary method of treatment employed. In practice, finding alternative materials and furnishings that have low pollutant emission rates has not often been an easy task.

Silver (1978) recommends that persons having adverse health symptoms in the home conduct a full cleanup of all items and portable furnishings in the home that are contributing to indoor air pollution. He stresses that synthetic foams and textiles, and soft vinyl imitation leathers can be most troublesome.

As discussed in Section 1.2.18, the primary concern regarding furnishings and materials is not necessarily the amount of contaminant released from each individual source, but rather the total mix of contaminants in the fully furnished home. Consumer education about the possible hazards may therefore be as important as monitoring and regulation of individual products.

1.5.7 Intrusion of Outdoor Pollutants

Description:

Air pollutants present in the outdoor air enter living spaces by ventilation and infiltration.

Pollutants Produced:

Stationary outdoor combustion sources (e.g. factories, furnace residential chimneys, municipal power generation plants) add the following contaminants to outdoor air, either directly or through the action of sunlight in photochemical smog (Hollowell, 1981, p. 4):

Sulphur Dioxide (SO2)
Carbon Monoxide (CO)
Nitric Oxide (NO)
Nitrogen Dioxide (NO2)
Ozone (O3)
various hydrocarbons
particulates

Motor vehicles, including cars, buses, and trucks, contribute primarily the following pollutants to outdoor air, and by infiltration, to indoor air (Hollowell, 1981, p. 4):

Carbon Monoxide (CO)
Nitric Oxide (NO)
Nitrogen Dioxide (NO2)
Lead (Pb)
particulates

The storage of motor vehicles in garages attached to or directly part of a home may lead to infiltration of automobile exhaust and various gases from gasoline, greases, oils, and components of heated engines. Wynder and Hoffman (1962, as reported in Severs, 1980) showed that the benzene extract of a gasoline engine exhaust condensate has about twice the carcinogenic activity of tobacco smoke concentrate. Benzo(a)pyrene was one of the chief carcinogens identified among the hydrocarbons present.

A third outdoor source is the soil itself, which produces radon (Hollowell, 1981, p. 4) and which together with vegetation also contributes moulds, pollens, and a variety of organic vapours to outdoor and by infiltration, to indoor air.

The California Department of Consumer Affairs (1982, p. III.B.14) notes that the next major contributor to human lead contamination after (old) leaded paint is lead in air, with leaded gasoline figuring as the major source of airborne lead nationwide. Many studies have shown a correlation between lead in motor vehicle emissions and lead in humans. City dwellers have been found to have significantly higher blood lead levels that suburban or rural populations, and children living within 100 feet of major highways have higher frequencies of elevated blood lead levels than children living in less trafficked areas.

House dust in urban homes has been reported to have a higher lead content than dust in suburban homes. Dust in homes closer to highways or lead smelters, foundries, or processing plants has been found to have a higher lead content than dust in homes farther away from such sources.

Barton (1981) reports 1979 ambient pollution levels in Canada as follows:

	number of cities	average of annual means	90% of cities below this level	maximum desirable
sulphur dioxide	69	12 ppb	18 ppb	11 ppb
nitrogen dioxide	34	26 ppb	34 ppb	32 ppb
carbon monoxide	42	1.7 ppm	3.2 ppm	5 ppm
ozone	39	15 ppb	20 ppb	15 ppb
suspended particulates	39	66 mcg/m^3	99 mcg/m^3	60 mcg/m^3

Discussion:

Outdoor pollutant levels are not constant, but rather follow daily cycles (Silberstein, 1977, 1979a) (see also 1.7.2 Decreased General Ventilation).

Yoshida et al (1974, p. 175) have indicated that the rate of occurrence of bronchial asthma in schoolchildren in Japan is greater in areas with high outdoor air pollution levels than in those with lower levels.

Colley and Brasse (1980, p, 52) reported on a multi-nation study comparing health indices of schoolchildren around the age of 10 years between areas of high outdoor air pollution and areas of low outdoor air pollution. In some countries no relationship between air pollution and respiratory disease and lung function was found, while in others there was a correlation. The pooled data shows that a close association exists between air pollution and various respiratory indices in children, and that smoke appears to have a greater effect on health than sulphur dioxide.

1.5.8 Use of Household Chemicals

Description:

In the average home occupants use a wide variety of household chemicals to assist in daily tasks such as cleaning.

Pollutants Produced:

Various organics and odours (Hollowell, 1981, p. 4). In office studies, which may involve similar compounds, Hollowell & Miksch (1981, p.6) identified aliphatic hydrocarbons, aromatic hydrocarbons, formaldehyde, amines, chlorinated hydrocarbons, and many other miscellaneous organics emanating from building maintenance products.

Emissions from aerosol spray devices include fluorocarbons, ammonia, and vinyl chloride (Hollowell & Traynor, 1978, p.2). McCarthy et al (1981) also tested various aerosols (room deodorant, bathroom cleaner, bug killer, hair spray and personal deodorant) and detected aluminum, sodium, chlorine, and vanadium.

Residues from carpet shampoos applied in concentrations in excess of manufacturers' recommendations have been responsible for health problems, particularly respiratory symptoms. (Kriess et al, 1981) A common detergent, sodium lauryl sulphate, is believed to be the irritant causing the problem.

Gosselin et al (1976) outline the components of various household cleaners and other chemical products. A few examples of some of the volatile and components are as follows:

abrasive cleaners	- may include chlorine compounds such as trichloroisocyanuric acid or sodium hypochlorite, and some brands may even include kerosene
alkaline cleaners	- may include up to 29% ammonium hydroxide
aluminum cleaners	- may include various organic solvents
copper cleaners	- may include various petroleum solvents
chrome cleaners	- may include ammonium hydroxide, alcohol, naphtha, or petroleum oil
detergents	- some may contain ammonia, alcohol, propylene or ethylene glycol, naphtha, petroleum solvents, pine oil and/or perfumes
deodorants	- may include propylene glycol or alcohol
stick deodorizers	- may include naphthalene, paradichlorobenzene or paraformaldehyde
spray deodorizers	- may contain alcohol, paradichlorobenzene, 1,1,1 trichloroethane, or formaldehyde
laundry starches	- may contain formaldehyde or pentachlorophenol
mildew proofing	- may contain pentachlorophenol, aromatic hydrocarbon solvents, methylene chloride or formaldehyde

../ (list continued)

lacquer thinners	- toluene and aliphatic hydrocarbons
floor polishes	- synthetic polymers or petroleum naphtha
furniture polish	- petroleum distillates and perfumes, wood preservatives
shoe polishes	- mineral spirits and turpentine

The reader is referred to the background reference for a complete list of possible components in the formulation of these and other household products.

Discussion:

Stewart and Hake (1976) describe an unsuspected hazard associated with the use of paint and varnish removers indoors. They reported that the main ingredient in most paint removers is methylene chloride (dichloromethane, CH_2Cl_2). Their experiments demonstrated that methylene chloride is metabolized to carbon monoxide and exposure to it increases the level of carboxyhemoglobin in the blood, blocking the uptake of oxygen and causing substantial stress on the cardiovascular system. They report that use of such paint remover for a period of three hours according to directions can easily produce a COHb saturation of 5% to 10%.

Elevation of the COHb to saturations greater than 5% can adversely affect patients with angina pectoris or cardiovascular disease. The elevated level of COHb from paint remover exposure lasts longer than that produced by inhalation of carbon monoxide, and is even further prolonged when methanol is present in the paint remover, as it is in some formulations. The authors stress the danger of such exposures to persons with coronary heart disease, particularly when combined with or followed by smoking.

While household cleaners, paint removers and other chemicals are used only intermittently and cautions are often included on the labels regarding the use of adequate ventilation, experience with chemically susceptible persons indicates that they can nonetheless be the cause of much discomfort.

Silver (1978) conducted tours of a number of homes in which occupants experienced illness thought to be related to the building or it contents. In most cases one or more boxes were filled with various loose bottles and cans of poisonous and often volatile household products and disposed of. Silver emphasizes that a basic rule for preserving indoor air purity is to keep the use or storage of volatile substances to an absolute minimum.

The California Department of Consumer Affairs (1982, p. III.G.24) sums up the dangers of household chemical use as follows:

> "Household chemical products, although effective and convenient, are significant contributors to the pollution of indoor air quality. The use of such products poses a serious threat to the quality of human health. The degree of threat is beyond what we are currently able to determine."

1.5.9 Consumer Appliances

Description:

The modern Canadian home has a host of electric consumer appliances, from vacuum cleaners to toasters and blenders. Each is a contributor in at least a small way to indoor air pollution. Combustion equipment will be dealt with in a subsequent section.

Pollutants Produced:

Demas and Johnston (1975, p.1,7) investigated the outgassing products during the normal and overheated operation of a 10 hp. electric motor with varnish wire and slot cells and phases insulated with an aromatic polyamide paper. At normal operating temperature (73 deg. C, 163 deg. F) the outgassing products included toluene, o-xylene, m-xylene, formaldehyde and other aldehydes, and nitrogen oxides. At 140 deg. C, an overheat condition, emissions of these gases increased substantially and benzene was also detected. At even higher temperatures, representing bearing failure, hydrogen cyanide and carbon monoxide were also measured.

While motors of this capacity are not found in residential situations, the materials found in furnace fan motors (typically 1/4 to 1/3 hp.), vacuum motors, and various other small household motors are similar, and occasionally overheat conditions may occur. No conclusions about the likely residential concentrations of these gases can be inferred from the study, which was performed within a laboratory collection chamber. Randolph (1962) and Zamm (1980) have noted that a number of persons may be susceptible to the gas-off products of the electric motors commonly found in homes.

The California Department of Consumer Affairs (1982, p. III.F.13) cautions that while the pollutants from self-cleaning ovens have not been measured, they may be high. Self-cleaning ovens run for long periods at high temperatures, and the process often produces irritating odors such as polynuclear aromatic hydrocarbons which can result in closing off the kitchen from the rest of the house.

The emission of ozone from badly maintained electrostatic air filters has already been mentioned (see Section 1.2.5 "Ozone").

Discussion:

The trend toward greater consumer use of electronic items has also introduced new sources of indoor air pollution. Little has been done to identify specific pollutants and quantify emissions, however. Clinical and personal experience communicated to this author indicates that television and stereo sets, radios and other electronic appliances gas off sufficient contaminants to severely affect people who have already become generally chemically susceptible. Television emissions may include ozone.

Further research in the area of chemical emissions from appliances may shed further light on the nature of certain illnesses already ascribed to certain devices. Media reports of headaches and other complaints related to the use of microwave ovens, for example, have attributed the problem to microwave leakage. Similar reports regarding the use of video display terminals in offices have concentrated on possible electromagnetic field hazards and X-ray emissions, but little has been measured that would appear to explain the health problems attributed to them. This author's experience, however, has indicated that there is sufficient chemical emission from either device to trigger adverse symptoms in susceptible persons. Often adequate venting of the appliance is sufficient to relieve symptoms.

Deliberate venting of polluting appliances is discussed further in Section 1.7.14.

1.5.10 **Spray Humidifiers**

Description:

Household humidifiers which either recycle their water or which include an open water reservoir which can stagnate can become sources of micro-organisms that will contaminate indoor air and may affect the health of household occupants. Assendelft (1979, p. 39) reports that allergic alveolitis has been associated primarily with evaporation and cool-mist atomizing humidifiers, but not steam humidifiers. He cautions that the micro-organisms multiply better in standing water, and that heat from the humidifier motor may be sufficient to create an optimum climate, but that regular cleaning and changing of filters should allow safe use of currently available humidifiers.

Pollutants Produced:

The micro-organisms produced include a wide variety of bacteria, fungi and amoebae. The proportions and species vary. Some investigations in the United States identified certain thermophilic actinomyces fungi as a cause of illness. In some British outbreaks amoebae were largely the cause (Brundrett, 1979, p.4).

Discussion:

Outbreaks are more common when such humidifiers are associated with an atmosphere which contains an organic dust. This dust, which is trapped by the recycling water sprays, forms nutrients for micro-organisms in the reservoir. The micro-organisms and their metabolites are then sprayed out into the atmosphere.

Control, particularly in the case of residential humidifers, consists of regular cleaning and changing of water. Sludge should not be allowed to form in the water reservoir (Brundrett, 1979, p.6,7). Once the mould spores start to multiply, not even a thorough cleaning with disinfectant is enough, and Assendelft (1979, p. 39) suggests full sterilization of the apparatus in an autoclave. Apparatus not in use for some time is especially dangerous.

The possible role of warm standing water in humidifiers in encouraging growth of Legionella bacteria has been mentioned in Section 1.2.12 "Bacteria and Viruses".

1.5.11 **Paints and Sealers**

Description:

The role of various paints and sealers in contributing to the overall level of organic contaminants in room air is described in a previous section (see section 1.2 under "Various Organic Vapours"). One additional contaminant that has been traced to certain paints is mercury.

Pollutants Produced:

Paint may release various organic gases, lead, and mercury (Hollowell, 1981, p. 4).

In a study of adverse health effects in the painting trades, Selikoff (1975, p. 94) notes that general painters are exposed to the following general groups of contaminants:

organic solvents	turpentine mineral spirits ketones aromatic hydrocarbons esters chlorinated hydrocarbons alcohols glycols
aerosols	chromium compounds (pigment) lead compounds (pigment) titanium dioxide (pigment)
isocyanates	

Householders and tenants are exposed to a lesser degree to the same array of chemicals.

Gosselin (1976, p. 160) lists the following as possible ingredients in typical latex wall paint for home use (the reader is cautioned that since these products change rapidly the list may not represent new paints produced in 1982):

fillers
titanium dioxide
inert filler pigments
polyvinyl acetate monomer
acrylic elastomer
styrene butadiene elastomer
lithopone
ethylene glycol
emulsifying agents
chlorinated phenols or o-phenyl phenols
water
vegetable oils or resins

'Mildew-resistant' paints in 1976 usually contained mercury compounds, such as phenyl mercury oleate, phenyl mercury acetate, or phenyl mercury succinate.

Varnishes and shellacs may contain the following (Gosselin, 1976, p. 161):

resins (alkyd, phenolic, polyurethane or other)
methyl alcohol
ethyl alcohol
gasoline
benzene
sodium hydroxide
turpentine
lead

Valbjorn, Nielsen and Kjaer found a connection between eye irritation, airway irritation, and emulsion paint on house walls. They also found a connection between dry upper airways and concrete as well as newly restored buildings. In dwellings where headache and airway irritation occur, they found that people were airing the dwelling 3 or more times per day, and that this was more often than persons without headaches or irritation. The dwellings in which eye irritation was noted were more frequently 0-4 years old, than older. Headache, dry upper airways and eye irritation were the three most common complaints among 627 occupants living in 240 dwellings.

Joselow (1978, p. 449) cites studies in which mercury vapour concentrations were measured in homes, offices and laboratories to be higher and in some cases 1000 times higher than ambient natural background levels. The emission of mercury from paints incorporating organic mercury compounds as fungicides and mildewcides is extremely slow and could last for years. Increased excitability of the central and autonomic nervous system has been reported at 10 mcg/m^3, and although all measurements taken were below this level, 4 to 6 mcg/m^3 were found in dentists' and doctors' rooms. Cases of mercury sensitivity from low-level exposure to other sources have been reported recently (Huggins, 1982) and suggest the need for further assessment of building material sources.

Hirschman et al (1963) describe a case of a 5-year old boy with generalized abdominal and muscle pain and general weakness, which was thought to be due to mercury poisoning from water-base house paint, possibly from both ingestion and inhalation. Laboratory analysis of his home surroundings revealed that the sleeping quarters had been painted four months before onset of symptoms, with a paint containing phenyl mercuric proprionate in a concentration of 0.036 per cent by weight, or 0.02 per cent by weight of mercury alone.

A test panel painted with the paint was subjected to analysis within a special testing 1.9 litre testing jar, ventilated at 1 litre per minute. The amount of mercury vapour from the freshly painted panel averaged 0.50 micrograms of mercury per minute per square foot of panel surface over the first thirty minutes. The panel continued to emit mercury vapour in diminishing amounts for six weeks despite continuous air changes. Calculations indicated that a freshly painted room (4 walls painted) of 800 cu. ft., ventilated at two air changes per hour, would have an average concentration of 0.21 mg. of mercury per cubic metre of enclosed air. The standard for continuous adult exposure without toxic effect at that time was 0.10 mg. of mercury per cubic metre. The authors note that there is a wide variation in individual susceptibility to mercury, and that in some cases very small doses might be significant.

Ware (1978, p. 100,101) reports that a host of organic mercury compounds have been used over the last thirty years, but that these have been largely replaced now by other organic fungicides. The U.S. Environmental Protection Agency banned most organic and inorganic mercurial fungicides for use in the home and for agriculture in the late 1970s, because of the toxicity of mercury to warm-blooded animals and the accumulation of mercury in the environment.

Foote (1972) measured mercury vapour concentrations in home, office and laboratory environments, and found mercury concentrations significantly higher than those in the natural environment. The amount of mercury in homes and offices was dependent upon the type of paint used and the length of time that had elapsed since the room was painted. Mercury concentrations were found in homes three years after painting with latex-base interior paint containing diphenyl mercury dodecenyl succinate to prevent fungus growth, at levels of 0.07 mcg/m^3.

Foote found that the mercury levels within homes that had been painted 7 days before testing had levels up to 3 mcg/m^3. Levels in doctors' office where a mercury thermometer had been broken (some time in the past) ranged from 4.6 to 5.7 mcg/m^3. Typical outdoor concentrations in three cities were around 0.03 mcg/m^3.

Spedding and Hamilton (1982) noted that a room containing mercury droplets (as from a broken thermometer) reached levels of 300 mcg/m^3 and that conncentrations in closed boxes or cupboards rapidly reach the equilibrium vapour pressure of 13.2 mg/m^3. The Threshold Limit Value in air for mercury is 50 mcg/m^3. They measured the absorption of mercury vapour by various indoor surfaces, in order to pursue the question as to the fate of mercury vapour deposited in the indoor environment in earlier years when precautions to reduce its concentration were not as strict as at present. PVC floor coverings were found to have a very high absorption rate. Paints, wallpaper, particleboard, carpets, and fabrics all absorbed mercury at varying rates, and the half-lives for desorption were also variable, some more than three months. Practical conclusions from this work include the need for at least moderate ventilation following a mercury spill to hasten the desorption of mercury from indoor surfaces.

Discussion:

Sealants used in homes where occupants are already chemically susceptible can compound problems rather than solve them. Outgassing products of the sealant itself can elicit adverse symptoms, and problems have been encountered with paints, urethanes, epoxies, and plastic vapour barriers. The use of alternative methods of avoiding primary pollutants (e.g. by venting channels adjacent to polluting materials) can be used, or sealant alternatives tested for individual reactions until a suitable substitute is found (e.g. aluminum foil barrier instead of plastic). (Small, 1982).

Zamm (1980, p. 57) reports that some sensitive individuals can detect paint fumes for three months or more after application. He particularly cautions chemically susceptible persons against using epoxy paints, because they take an exceptionally long time to dry and must be aged for three to six months prior to exposure to the chemically susceptible persons (Zamm, 1980, p. 110). The U.S. National Institute for Occupation Safety and Health (NIOSH) cautions paint and other manufacturers that epoxy resins used in protective coatings should be regarded and handled as dangerous materials. Certain individuals may develop an allergic reaction to even trace amounts of epoxies.

Selikoff (1975) investigated the health hazards in the painting trades, and found not only a high rate of illness and neurotoxic disorders but also a high rate of on-the-job accidents. Central nervous system effects of the volatile solvents to which the painters were exposed included dizziness, light-headedness, unusual exhilaration, loss of balance, and feeling 'high'. Digestive symptoms such as nausea, vomiting and loss of appetite were common, and loss of consciousness was also reported in a significant number of painters. Prenarcotic symptoms were reported by 84% of workers who had used epoxy paints, compared with 60% of workers who had never worked with epoxy paints.

The significance for the householder lies not only in the long-term effect of low levels of these same solvents, but with infrequent but concentrated exposures during do-it-yourself painting and remodelling efforts. There is both a health hazard and a safety hazard involved in painting without very high levels of ventilation. Further discussion of indoor air pollution as a safety hazard can be found in another publication by this author (Small, 1982b).

1.5.12 Insulation

Description:

Various types of insulation used in housing have been reported to contribute in varying degrees to indoor air contamination. In 1980 approximately 82% (in dollar terms) of the home insulation market in the U.S. was accounted for by fiberglass. Rock wool had a market share of about 11%, Cellulose 5%, and other types, 2%. (Frost and Sullivan, 1982).

Urea-formaldehyde foam insulation (UFFI), now banned in both Canada and the United States for housing application, was responsible for widespread recognition of indoor pollution from formaldehyde sources, including UFFI.

The effects of UFFI gases are documented in considerable detail in other reports (see Small, 1982a) and will not be discussed further here.

Pollutants Produced:

Formaldehyde, fiberglass (Hollowell, 1981. p. 4).
Borates (Buscher, 1982).

Health Effects:

Buscher (1982) reported on three families in whom various symptoms had appeared soon after installion of cellulose insulation, including respiratory difficulties, skin rashes, depression and gastrointestinal problems. Air concentrations of borons were measured and found in one case to be .6 mg/m^3 (US Threshold Limit Value is 1 mg/m^3). Elevated boric acid levels were also detected in the urine. Boric acid is commonly used as a fire retardant in cellulose insulation. Concern was expressed about air contamination caused by the use of recycled newspapers in the manufacture of the insulation, since newsprint and ink contain a wide variety of organic chemicals and heavy metal compounds (although no measurements were cited).

Calabrese (1980) quotes Tabershaw et al (1977) as having reported that workers involved in the manufacture of boric acid have been reported to exhibit some atrophic changes in respiratory mucous membranes, weakness, and joint pains, although the mechanism for such toxic responses remains to be elucidated.

The California Department of Consumer Affairs describes a state Transportation Department building in Maine in which occupants experienced a variety of symptoms including rashes, watery eyes, hoarseness, coughing, dizziness, lethargy, sores that would not heal, breathing problems, stiff shoulders and necks, and coughing up of blood. The building air supply was found to contain minute particles of fibrous glass, from fibrous glass air ducts.

Newball and Brahim (1976) report an exposure to fibrous glass from a domestic air conditioning system, in which several members of a family experienced severe respiratory symptoms and were forced to abandon the home until the source was eliminated (air conditioning ducts lined with fibrous glass). Bronchial washings confirmed the presence of fibrous glass in the lungs. The authors conclude that fibrous glass exposure from air conditioner systems may be a serious domestic problem. They note that once glass fibers have entered the house and become entrenched in the carpets, rugs, draperies, upholstered furniture and mattresses, etc., the only effective way to eliminate the glass fibers is to discard the contaminated materials.

This author has received a small number of additional case reports of illness associated with the use of fiberglass insulation, usually involving incomplete installations where the material is still exposed. The material does outgas at sufficient rates, particularly when heated to summer attic or outside wall temperatures, to cause symptoms in chemically susceptible persons. Care in forming complete air and vapour barriers is recommended.

Although no formal tests have been undertaken, a small number of reports and personal experiences by this author indicate that under some circumstances (for example when a wall is exposed to late afternoon sun on warm summer days) outgassing from styrofoam insulation or even from fiberglass may also be sufficient to affect chemically susceptible persons.

Discussion:

Stanton (1972, as reported in Selikoff, 1974, p. 62) observed experimental mesothelioma with several varieties of fine fibrous glass. This raises the possibility, as yet unproven, that exposure to fine particles from fiberglass insulation could pose some cancer risk.

1.5.13. Occupants' Activities

Description:

Normal processes of living and respiration by people and their pets generate a number of gases and particles. (Hollowell, 1981, p.3) Very few daily activities do not involve addition of pollutants to indoor air in some form. Everything from opening the mail, reading a newspaper watching television or putting on makeup, to preparing and cooking food can affect indoor air. Numerous examples have already been given in previous sections.

Lipmann, M. (1979, p. 39) notes that modern hobby activities involve materials that were previously only associated with industrial activities. Part-time potters use kilns and torches which can produce toxic aerosols in large quantities. Artists and artisans of all types use substantial amounts of solvents, pigments, glazes, epoxies, acids, alkalis, and plastics. These materials are frequently used without the precautions or controls generally practiced in industry.

Pollutants Produced:

Metabolic gases produced include: carbon dioxide, water vapour, ammonia, various organics and odours. Various microbes are also dispersed (Hollowell, 1981, p.3,4). Johansson (1977, p. 1371) identified significant increases in the concentrations of acetone and C2-alkylbenzenes in occupied rooms compared to unoccupied rooms.

Since few measurements have been done specifically to monitor occupant activities, the only general description of the products that are produced that can be offered at this point is 'various organics and odours' (Hollowell, 1981).

Discussion:

Mathews (1978) notes that in some highly sensitive patients respiratory symptoms can be produced by exposure to the airborne food molecules in fish odours. This is also a commonly reported phenomenon among persons with multiple food allergies, and is also recognized as a problem for some women during pregnancy, particularly in the early stages. Clinical experience reported to this author also indicates that some highly susceptible persons may react to the odours of food or drugs from others who have recently consumed them.

Design of clean dwellings must necessarily take into account the wide variety of activities that take place in the home, the products and chemicals involved, and the potential for pollutant accumulation and health effects. Consumer education may be important in alerting people to the importance, for example, of adequate ventilation during certain hobby activities.

1.5.14 Pollutant Sources: Summary Table

Section/Pollutant Source	Summary
1.5.1 Improper Chimney Construction	Improperly lined chimneys may corrode from the exhaust of a natural gas furnace, leading to blocking and potentially fatal carbon monoxide accumulation in a home.
1.5.2 Gas Stoves	Gas stoves are major producers of carbon monoxide and nitrogen dioxide at rates which are harmful to health.
1.5.3 Kerosene Heaters	Portable unvented kerosene heaters produce carbon monoxide and other gases at levels considerably above outdoor standards, under normal operation.
1.5.4 Fossil Fuel Furnaces	Improperly installed or maintained fossil fuel furnaces can contribute to indoor air pollution, sometimes at dangerous levels. Chemically susceptible persons are more quickly affected by small leaks than others.
1.5.5 Wood Stoves	Burning wood can lead to high indoor pollutant levels if stoves are not well sealed or carefully operated. Infiltration of second-hand wood smoke from neighbouring chimneys can also increase indoor pollution significantly.
1.5.6 Furnishings	Many furnishings and decorative materials in the home are responsible for the presence of different organic contaminants in indoor air. While each individual source may appear innocuous, the total pollutant load may be significant for many people, and can definitely cause harm to those who are already chemically susceptible. Alternative products are needed.
1.5.7 Outdoor Pollution	Infiltration of various outdoor pollutants, especially car exhaust from adjacent roads and radon gas from soil beneath a home may present long-term health problems.
1.5.8 Household Chemicals	Many household products (e.g. cleaners) contribute significant quantities of organic chemicals to indoor air, and have been reported to trigger adverse symptoms in susceptible persons. The total load is important.
1.5.9 Appliances	Numerous small household electrical appliances give off a variety of organic chemicals and odours. Some may be significant sources of indoor pollution and are known to affect susceptible persons.

../(list continued)

1.5.14 Pollutant Sources: Summary Table (continued)

1.5.10 Humidifiers	Household humidifiers which either recycle their water or which include an open water reservoir which can stagnate can become sources of micro-organisms that will contaminate indoor air and could affect health.
1.5.11 Paints	Paint and sealers may release various organic gases, lead, and mercury. Some sensitive individuals can detect paint fumes for three months or more after application. Neurotoxic effects during painting may also increase risk of accidents.
1.5.12 Insulation	Various types of insulation in addition to Urea-formaldehyde foam have been reported to cause some problems particularly for already susceptible persons. Styrofoam, cellulose, and fiberglass are cited.
1.5.13. Activities	Normal processes of living and respiration by people and their pets generate a number of gases and particles. Very few daily activities do not involve addition of pollutants to indoor air in some form. Hobby activities often involve highly toxic materials.

1.6 FACTORS AGGRAVATING INDOOR AIR POLLUTION

The literature was searched for evidence of specific factors which tend to cause the accumulation of indoor air pollution. Most of the recent literature concentrates on the role that energy conservation methods such as tightening of houses and reduction of ventilation rates have played in increasing indoor pollution levels.

As with the previous sections, the discussions following are meant as a brief introduction to the literature. This author would be grateful to receive any further references on these and other related topics that readers have found useful.

Sub-Index of Factors Aggravating Indoor Air Pollution

	page
1.6.1 Tightening of Houses and Reduced Ventilation	130
1.6.2 Increased Humidity and Temperature	131
1.6.3 Other Factors	133

1.6.1 Tightening of Houses and Reduced Ventilation

Description:

In order to conserve heat, houses are being 'tightened' by sealing cracks, installing windows and doors, with fewer leaks, and generally stopping as much air infiltration as possible at every possible inlet.

How Pollution is Increased:

Older houses and new housing that is not well sealed for energy conservation purposes have natural air exchange rates on the order of 0.8 to 1.5 air changes per hour. The random introduction of outdoor air by infiltration (through cracks in the bulding envelope), or its regulated introduction by natural ventilation (opening doors and windows) or mechanical ventilation (fan and duct systems of varying complexity), is the usual way in which building occupants are protected from the accumulation of undesirable indoor air contaminants (Hollowell, Berk and Traynor, 1978, p.1). This level of infiltration has, until the advent of more tightly sealed housing, provided a natural limitation on the buildup of pollutants in indoor air (Hollowell and Traynor, 1978, p.6).

Well-constructed new single family houses have air exchange rates (ventilation + infiltration) on the order of 0.5 to 1.0 air changes per hour. Methods of sealing homes to allow air exchange on the order of 0.2 to 0.5 are being developed and have been applied in a small number of new energy-conservative homes (Hollowell and Traynor, 1978, p.5). This restriction of ventilation allows a buildup of indoor pollutants.

Korsgaard (1981) also indicates that tightening a home may increase humidity and therefore the likelihood of higher dust mite populations.

Discussion:

Reduced infiltration and ventilation rates in buildings can lead to elevated levels of indoor-generated air contaminants (Hollowell, Berk and Traynor, 1978, p. 1). Cain (1979, p. 258) concludes that a 30% reduction in ventilation rates for new buildings will cause roughly a 43% increment in concentration of indoor contaminants and a 20% increment in perceived odour, based on a theoretical formula developed by Turk (1963).

Hollowell, Berk, Brown et al (1981) state that their studies of new energy-efficient residences (with air exchange rates lower than 0.4 ach) indicate that indoor levels of radon, formaldehyde and particulates sometimes exceeded existing (U.S.) guidelines or standards for outdoor air, due to a number of factors, such as geographic variation of radon content in soil, indoor furnishings, and occupant activities. On the other hand, they have also studied three retrofitted houses where no pollutants reached levels approaching health guidelines or standards.

1.6.2 Increased Humidity and Temperature

Description:

Variations in humidity in dwellings can significantly affect the levels of pollutants and allergens that may influence the health of the occupants. Major indoor water vapour sources are metabolic and respiratory processes, combustion (esp. natural gas), and evaporation from clothes, dishwashing, and bathroom functions (National Research Council U.S., 1981, p. ES-9).

Demas and Johnson (1975, p.1) note that some synthetic polymer products of various chemical compositions have low heat resistance, and that increased temperature of these products can result in solvent and additive outgassing and molecular degradation, producing volatile organic and inorganic products. Emissions from materials in an electric motor under normal and overheated conditions were given as an example in a previous section (see section 1.5 under Consumer appliances).

How Pollution is Increased:

Korsgaard (1981) compared identical apartments, half of which were retrofitted with tightly sealed window units. He observed a significant increase in humidity in the sealed apartments in the February-March period, and a higher concentration of house dust mites in dust and in mattresses in the sealed compared to the unsealed apartments.

Excess humidity in dwellings with leakage of air through the building envelope can cause condensation within the walls during colder months. This promotes the growth of mould, algae and fungi, and may cause structural damage (e.g. spalling of brick) which may further increase air leakage.

High relative humidities increase formaldehyde and other emissions from materials such as particleboard (National Research Council US, 1981, p. I-7). However, odours, particles, and such vapours as acrolein may be more irritating at low relative humidities.

There are a number of common conditions which may raise the temperature of materials in the home and thereby cause a higher gassing-out rate than would otherwise occur. For example, a south or west window may allow sunlight to strike synthetic curtains or carpeting, or foam-filled furniture cushions. Even window gasketing and glazing strips may give off detectable odours when in direct sunlight.

Plastic housings for consumer appliances and electronic devices (e.g. television sets) will also heat up as the appliance is used. Some portable heaters have many plastic components which gas out considerably at high temperatures, and sometimes furnace installations involve plastic taping on hot ducts. Plastic-coated wiring and rubber door seals on cooking appliances also contribute more contaminants to indoor air when heated.

Discussion:

The higher concentrations of house dust mites and fungi in houses that have been tightened up for energy conservation could increase the number of people with active allergic disease. Lowenstein (1979, p. 126) stresses that a relatively large part of the population are potential allergics.

Condensation on materials and furnishings increase the corrosive effects of absorbed gases. (National Research Council U.S., 1981, ES-9).

1.6.3. **Other Factors**

Description

In the same manner as outdoor photochemical smog is produced, i.e. by action of ultraviolet light on hydrocarbon and other pollutants, indoor smog may also be generated in the presence of artificial lighting sources which emit utraviolet light. This hypothesis is proposed by Sterling and Sterling (1981).

Although the literature in the area of causative factors was sparse, two other major factors should be mentioned:

1) crowding - the likelihood of indoor pollution goes up with number of people in any space. Venting should be matched to the occupancy to avoid buildup of dangerous contaminant levels

2) new materials - the introduction of hundreds of new materials into the average home in the last two decades, without sufficient awareness of their pollutant emission characteristics, has contributed substantially to the present indoor air pollution problem .

1.7 FACTORS REDUCING INDOOR AIR POLLUTION

The indoor air pollution literature was searched for evidence of specific factors which tend to reduce accumulation of indoor air pollution. The information presented is meant only as a brief introduction to the literature.

The fact that some sections are particularly sparse reflects the lack of information available at this time. The science of low-pollution design is very much in its infancy and requires a great deal of further work before it can be said with confidence that we know how to build unpolluted dwellings in Canada. Further discussion of low-pollution design is presented in Section 2 "Low-Pollution Design and Construction".

This author would be grateful to receive any further references on these and other related topics, that readers have found useful.

Sub-Index of Factors Reducing Indoor Air Pollution

	page
1.7.1 Increased General Ventilation	135
1.7.2 Decreased General Ventilation	140
1.7.3 Adsorption on Interior Surfaces	142
1.7.4 Gassing-out Period	143
1.7.5 Use of Low-emission Materials and Systems	144
1.7.6 Source Removal	145
1.7.7 Modification of Combustion Processes	146
1.7.8 Changes in Building Design and Construction Practices	147
1.7.9 Changes in Building Maintenance Practices	148
1.7.10 Air Filtration	149
1.7.11 Use of Sealants	151
1.7.12 Adjustment of Product Formulation	152
1.7.13 Treatment of Final Product	152
1.7.14 Ventilation of Specific Sources	153
1.7.15 Human Factor Control	154
1.7.16 Warning Devices & Controls	154
1.7.17 Summary Table	155

1.7.1 Increased General Ventilation

Description:

Hollowell, Berk and Traynor (1978, p.1) assert that the primary engineering control for the maintenance of indoor air quality is ventilation, i.e. the use of controlled flows of air to lower the levels of air contaminants by:

1) dilution with fresh outside air, and
2) the use of recirculating systems incorporating chemical and physical contaminant control devices, or
3) a combination system employing both dilution and recirculation.

Increasing ventilation for dilution can be achieved by opening windows and doors, or by installation of mechanical ventilation and heat exchanger systems, to increase the frequency of air change in a residence.

Opening windows can provide efficient general ventilation in mild weather, when heating and cooling systems are turned off. Mechanical ventilation can be under variable control, and ultimately might be regulated by air quality detection (Hollowell, 1981, p.8).

Applicability:

Jonassen (1981b) recommends simple ventilation or air exchange with radon-free or radon-poor air as an effective remedy to the buildup of radon and radon daughter products. He notes that for commonly encountered air exchange rates the radon concentration will be inversely proportional to the air exchange rate, with 1 air change per hour corresponding to a radon concentration of 0.75% of the unventilated maximum value. This means that even with a high influx of radon, ventilation rates on the order of 0.5 to 2 times per hour may be sufficient to keep the radon concentration reasonably low.

Lundqvist (1979, p. 276) conducted experiments which indicated that a ventilation rate of 60-80 m^3 of fresh air for each cigarette smoked is necessary to eliminate the tobacco smoke from the room before its adsorption on room surfaces, depending on the volume and characteristics of the room.

Advantages:

Air-to-air heat exchangers preheat the cold incoming air in winter by transferring heat from the warm outgoing air, allowing 50-80% of the energy normally lost in the exhaust air to be recovered. The same process works in reverse in the summer air-conditioning season (Hollowell, 1981, p. 9). Persily (1981) measured the efficiency of a popular portable (window-unit) heat exchanger and found it to be 50%.

Regulation of ventilation by some kind of air quality detection and control system may provide greater energy efficiency by avoiding over-ventilation, and better average air quality by avoiding under-ventilation during indoor activities generating high pollutant concentrations. It should be noted, however, that there is some difficulty in determining a universal surrogate indicator of air quality (e.g. carbon dioxide) which will be adequate in a wide variety of circumstances (Russell, 1982).

Disadvantages:

General ventilation represents a major energy loss, and minimal ventilation is a good means of energy conservation.

Use of windows (e.g. in kitchens and bathrooms) instead of mechanical ventilation allows pollutants to diffuse throughout the residence while being diluted and flushed out of the building (Hollowell, 1981, p. 9).

Hollowell and Traynor (1978, p.2) note that sometimes 'fresh' outside air may be more contaminated than indoor air, rendering it either unpleasant or dangerous to use for ventilation. Under some circumstances, then, exclusion, reduction or treatment of outside air must sometimes be considered. As noted in Mohr (1982), particularly at night high concentrations of wood smoke are found in outdoor air in some communities. In this author's experience such conditions make it nearly impossible for persons who are chemically susceptible to rely on adequate ventilation alone to reduce indoor air contaminants. Source removal and often indoor air filtration are necessary before one can safely reduce ventilation rates to avoid such outdoor pollution episodes.

While in most cases it would appear that indoor air is almost always more polluted than outdoor air, individual susceptibility alone may determine which is more significant to a person's health. For example, it is known that some persons with multiple allergic sensitivities may be far better able to withstand high levels of organic pollutants indoors, than even low levels of moulds or pollens outdoors, even if on balance the air outdoors is 'cleaner'. The reverse also holds with others. Sometimes reactivity is specific enough that one component of a periodic industrial pollution episode, even at low concentrations outdoors, may trigger sufficient adverse symptoms in a susceptible persons to warrant a complete shutdown of ventilation until it has passed, even if other pollutant levels inside increase.

Discussion:

A mechanical ventilation system with an air-to-air heat exchanger can be installed in walls or windows, or as part of a central air system. Unless there is good air movement throughout the house, however, a heat exchanger may ventilate only the room in which it is installed. Two or more may be required for a large house. The estimated cost (1981) for small window units is about $300 (in United States), uninstalled. For systems intended to ventilate an entire house, installation costs can vary, depending upon the amount of duct work necessary (Hollowell, 1981, p. 9).

For chemically susceptible persons, some caution is advised in investigating air-to-air heat exchangers, for at least two reasons:

1) heat exchange surfaces (membranes) may add minute quantities of gases into the intake air stream

2) in cold climates some models shut off all intake air during a defrost cycle. Full control over 'on' and 'off' periods may be necessary for the hypersusceptible.

The question of 'ventilation efficiency' is also being investigated. It must be remembered that a quoted air change rate may not apply uniformly to a whole house or even a whole room. Studies in large office complexes have suggested that under some conditions fresh air supplies may not mix adequately with room air before reaching the exhaust outlet. Early results of some experiments in residences, however, indicate on the other hand that the level of air mixing may be relatively good (Grimsrud, 1982).

Hollowell, Berk and Traynor (1978, p.2) note that the level of fresh air required for the health, safety and comfort of building occupants is not widely agreed upon. Ventilation standards within the United States may vary by a factor of five for the same type of space, depending on the local code and the building use. Standards are generally conservative, and since they have been developed by a wide variety of groups, they frequently vary for the same application. The problem of achieving the highest possible energy conservation has led to a re-examination of ventilation rates with the aid of more precise measurement of indoor contaminants.

As an important exercise in understanding the effects of ventilation, the reader is referred to Bridbord et al (1975), who calculate the changes in concentrations of gases with different air exchange rates, according to a theoretical decay model assuming best possible mixing of gases. If concentration of a pollutant (assumed to be completely mixed in the room air) is C at time zero, the following table specifies the concentrations at later times under different exchange rates:

Concentration at various exchange rates

Time, min.	Once per hour	Twice per hour	Six times per hour
0	C	C	C
15	0.88C	0.78C	0.47C
30	0.78C	0.61C	0.22C
45	0.69C	0.47C	0.11C
60	0.61C	0.37C	0.05C
90	0.47C	0.22C	0.01C
120	0.37C	0.14C	lt 0.01C
150	0.29C	0.08C	--
180	0.22C	0.05C	--

This table illustrates rather dramatically that at one air change per hour, a pollutant level, for example, caused by spraying an aerosol product, will diminish only to 80% of the original concentration after 30 minutes, and that even after three hours the concentration is still above the 20% level. Even with six air changes per hour it takes one and a half hours to reduce the pollutant level to 1% of the original level, assuming even mixing of the air.

It is important also to distinguish between human perception of 'stuffiness' and the buildup of indoor air pollution. Cain (1979, p. 210) states that in the late 19th century, many scientists thought that an unventilated room became stuffy because of an increase in toxic, airborne contaminants. At the beginning of the 20th century, however, scientists discovered that stuffiness was almost strictly a thermal, rather than a chemical, matter. Persons would remain in a sealed, unventilated chamber for hours without complaint, if the air were kept cool. By contrast, persons would complain bitterly about the stuffiness of a well-ventilated, but hot and humid chamber.

Offerman et al (1982) measured indoor air quality in tightly-sealed homes in Rochester, New York. In nine selected houses, air-exchange rates without mechanical ventilation were between 0.2 and 0.5 air changes per hour. Measurements of radon gas, formaldehyde and nitrogen dioxide were below existing guidelines. Mechanical ventilating systems with heat exchange were effective in further reducing indoor contaminant levels. The researchers conclude from these measurements that it is possible to make houses energy-efficient without causing unacceptable indoor air quality, if the source strengths of contaminants are low.

Radon gas measurements varied from less than 0.2 pCi/l to 2.2 pCi/l, all below a guideline level of 0.02 WL which would be equivalent to from 3 to 6 pCi/l depending on the equilibrium factor between radon and its daughters. Formaldehyde measurements varied from 7 ppb to 64 ppb, all below guideline levels of 100 ppb. Houses with the highest formaldehyde and total aldehyde levels were also the only houses in the sample with significant amounts of new particleboard.

Nitrogen dioxide measurements revealed higher levels in houses with gas cooking appliances compared with those having electric cooking appliances (14.7 +/- 7.2 ppb compared with 4.1 +/- 3.9 ppb). Even the measurements in the houses with gas cooking appliances were considered low relative to the data of other researchers, and were attributed to the use of outside-vented range hoods by the occupants. The indoor NO2 measurements were consistently lower than outdoor concentrations (which varied from 10-30 ppb) except for one home which had an unvented gas dryer as well as a gas cooking range.

Particulate concentrations measured in two houses were twice the outside levels. The presence of tobacco smokers in both houses was suggested as the likely cause of this. The levels of inhalable particulates were

76 and 52 mcg/m^3 respectively in the two houses. The U.S. outdoor standard for total suspended particulates is 75 mcg/m^3, but the researchers caution that indoor and outdoor particulates differ significantly in size and composition and the levels may not therefore be comparable.

With mechanical ventilation, average air exchange rates increased 80%. The average indoor radon concentration was reduced 50% and the average formaldehyde concentration was reduced 21%. Nitrogen dioxide levels increased (from average 7 ppb to average 9 ppb). For the two test houses for which particulates were measured, increased ventilation reduced the average particulate concentration by 30%.

Formaldehyde levels in homes with sensible-heat type heat exchange units (without water vapour exchange) were reduced on average 30% +/- 20%. In homes with sensible-latent type heat exchangers (with water vapour exchange), there was virtually no change in formaldehyde levels. This may be attributable to the cross-stream transfer of formaldehyde along with the water vapour.

The extent to which ventilation is effective in controlling indoor contaminant concentrations depends largely on the reactivity of the contaminant. If the contaminant reactivity is very high relative to the air-exchange rate, it can be expected that in a well-mixed space either increasing or decreasing ventilation will have little effect on the steady-state concentration of indoor contaminants. Formaldehyde, nitrogen dioxide, suspended particulates, and radon daughters are significantly removed from indoor spaces by physical and/or chemical reactions with indoor surfaces. Thus the change in concentration resulting from increased or decreased ventilation will be less than the inverse of the change in air-exchange rates. The concentration of radon, a less reactive contaminant, rises and falls in inverse proportion to the air exchange rate.

The researchers conclude that one key to having an energy-efficient house with both low air-exchange rates and good indoor air quality is to construct and furnish it such that total emissions from indoor contaminant sources are low. They recommend that builders should be selective in choosing building materials that are not potential sources of indoor air pollution. In addition, occupants must accept responsibility for reducing other sources of contamination such as tobacco-smoking, use of unvented combustion appliances and toxic cleaning products, and selection of house furnishings constructed with urea-formaldehyde based resins. Radon source control was recommended including the avoidance of building materials with high concentrations of radium, aeration of supply water if taken from underground springs or wells, and reduction of air pathways from soil to basement areas.

1.7.2 Decreased General Ventilation

Description:

During peak outdoor pollutant episodes, e.g. CO, NO2, SO2, ozone, reduction of general ventilation in a home may be effective in postponing the buildup of pollutants, and when the outdoor peak is short-lived, reducing the level of the outdoor-generated pollutant that would otherwise have occurred indoors.

Applicability:

This technique has application in homes with few indoor pollutant sources, and during outdoor pollution episodes of high relative peaks and short duration, such as those generated during an urban rush hour. It is also used commonly to reduce mould and pollen exposure for sensitive persons, though often recirculating filtration and air conditioning take place simultaneously in this application.

Advantages:

Used alone, this technique is energy-saving, does not involve additional expenditure for filtration media, and is easily implemented by the homeowner by closing windows or reducing fan volume.

Disadvantages:

In homes with multiple indoor sources, the buildup of pollutants from indoor sources may outweigh any advantage of avoiding the outdoor peak. Homes with high natural infiltration rates (e.g. through cracks) do not allow as much control, although closing windows and shutting off fans brings infiltration to a minimum. If houses are shut up tightly in summer and not properly shaded the buildup of heat indoors may be excessive.

Discussion:

Outdoor pollutant levels are not constant, but rather follow daily cycles (e.g. nitrogen dioxide) and seasonal cycles (e.g. pollen count). Indoor concentration of pollutants generated solely outdoors also follows a daily cycle but its maximum lags behind and is lower than the oudoor maximum, to an extent in inverse proportion to the building's air exchange rate (the lower the air change rate, the greater the time lag and reduction of peak levels). Using a theoretical Fourier series model Silberstein (1977, 1979a) predicts that lowering a building's air exchange rate from 1 air change per hour to 1/4 air change per hour will protect its occupants from an outdoor peak pollutant concentration, if:

1) the outdoor peak or variation above its average is much greater than its average, and
2) the peak is short-lived.

The shorter the peak of the outdoor pollutant, the greater is the protection achieved by lower air exchange rates.

However, the comparison between protection from outside pollutants and increased generation of inside pollutants, by this model, is unfavourable. An air exchange decrease from 1 acph to 1/4 acph during a 1 1/2 hour peak outdoor pollutant episode would yield a 2 to 3-fold lower indoor peak of the oudoor pollutant, but a 2 1/2 to 4-fold higher long-term average concentration of pollutants due to indoor sources.

Silberstein concludes that the increase of concentration of pollutants from indoor sources is a more significant effect than the reduction of potential peaks of outdoor sources. The exercise suggests, however, that in homes with few indoor sources, the ability to decrease total air change during short-lived outdoor peaks such as from rush-hour traffic might be beneficial. The reader is referred to the background reference for the detailed assumptions in the model (Silberstein, 1977, 1979a).

1.7.3 Adsorption on Interior Surfaces

A number of air contaminants either react with or are absorbed by the various surfaces within a room, both of building materials and furnishings (Crawshaw, 1978, p. 15). Porous surfaces such as brick, concrete, unfinished wood, non-plastic wallpapers and fabrics will all absorb pollutants to some extent. For example, Crawshaw describes wool carpet and cellulosic wallpaper as practical absorbers that can be used to deliberately lower indoor concentrations of sulphur dioxide.

Cox and Plenkett (1972) reported that the deposition velocity of SO2 onto a gloss painted surface increased by a factor of 33 as the relative humidity was increased from 30 to 86%. Ozone uptake by aluminum increased by a factor of 3 as the humidity increased from 32 to 83%.

Information has been presented concerning the accelerated adsorption of tobacco smoke on room surfaces in the presence of a negative ion generator in Section 1.2.7 "Tobacco Smoke". Adsorption of mercury vapour by furnishings and room surfaces was discussed in Section 1.5.11 "Paints and Sealers".

1.7.4 Gassing-Out Period

Hollowell & Miksch (1981, p. 7) suggest that further research may define acceptable 'waiting periods' prior to occupancy of buildings or periods of high ventilation rates during which new building materials gas out.

Zamm (1980) has advocated a gassing out period of three to six months for certain paints and sealers prior to use of premises by persons known to be highly chemically susceptible.

In this author's experience, there are some materials (e.g. certain types of latex paint, some polyurethanes, vinyls, etc.) that still remain active as pollutant sources for a decade or more after installation. While the amount of gas produced must certainly be small, it is known to affect those who have become highly susceptible.

Various methods of accelerating the gassing-off period of building surfaces have been suggested, and warrant further investigation, for example:

1) use of radiant heat to 'bake' interior paints and sealers
   (used industrially to dry and harden coatings)
2) ultraviolet light exposure
   (proposed but not tested)
3) exposures to alternately moist and dry conditions
4) continuous ventilation at very high levels

1.7.5 Use of Low-Emission Materials and Systems

Description:

Selecting materials, appliances, mechanical systems, etc. with lower emissions of pollutants than used previously in construction, furnishing or decorating (Hollowell, 1981, p.8).

Examples include the substitution of an electric stove for a gas stove. Hollowell and Traynor (1978, p.4) indicate that while high concentrations of gaseous indoor pollutants (e.g. CO, NOx) from gas stoves had been reported, no elevated levels of the same pollutants had been found from electric stoves.

Williams and Carhart (1975, p. 1), divide materials into two categories: 1) metallic and ceramic, and 2) organic. The first category does not normally present 'atmospheric habitability' problems because of their low volatility, and therefore represents a low-emission alternative, when feasible, to more organic materials which are characterized by outgassing or evaporation for extended periods.

Applicability:

Offerman, Hollowell and Roseme (1981) measured indoor air pollution levels of nine relatively tight houses in the Rochester, New York area, and found that concentrations were not in excess of (U.S.) guidelines. They suggest that the source strengths of pollutants in these houses were low and advise that when designing houses to have low air-exchange rates, builders should be selective in choosing materials that are not potential sources of indoor air pollution.

Discussion:

Experience in European countries and more recently in the United States indicates that manufacturers will respond to pollution concerns (and possibly to lawsuits) by developing alternate materials with lower gassing-off rates (e.g. low- formaldehyde particleboard).

Further discussion of alternate materials is given in Section 2 "Low-Pollution Design and Construction" in the context of the author's Sunnyhill Research Centre example.

1.7.6 **Source Removal**

Description:

Removal of the pollutant source. (e.g. particleboard, urea-formaldehyde foam insulation) (Hollowell, 1981, p. 9)

Discussion:

The California Department of Consumer Affairs (1982, p. IV.D.5) concludes that while ventilation, filtration, heat exchangers, hood vents, and other measures can contribute significantly to improved air quality indoors, the extent of the problem is determined largely by the extent of contamination which must be removed:

> "For that portion of contaminants generated by most building materials, substantial reductions are possible through control of sources strengths. Materials which are known to generate pollutants (such as formaldehyde and other organic compounds) can be pretreated or banned to reduce ventilation requirements and pollutant levels. Control of pollutants at the sources is the most effective measure. Ventilation and other measures should be considered only as secondary means of controlling indoor pollution."

Zamm (1980, p. 42) advises that the best defense against allergies is avoidance. He suggests that the best course of action is either to change the environment to weed out offending substances, or to change environments.

Complete removal of the pollutant source has been accomplished effectively for a number of known pollutants, including synthetic rugs, particleboard, and Urea-Formaldehyde Foam Insulation (UFFI). Readers are cautioned that 100% removal may be difficult in the case of substances like UFFI, and that in some instances pollutant levels after removal have been equal to or greater than those initially, possibly due to saturation of the insulation material into wooden wall studs (Shirtliffe, 1982).

There can also be difficulties in finding replacement materials that will not present further problems for persons who may already be generally chemically susceptible, and testing of individuals for reactions to alternative materials may be necessary (Small, 1982).

1.7.7 Modification of Combustion Processes

Maintenance, adjustment, or redesign of indoor combustion sources such as gas stoves, gas and oil furnaces, and space heaters may reduce emissions and/or ensure that emissions are properly vented to the outside air under all conditions (Hollowell, 1981, p. 9).

Other modifications possible (and now being introduced) include the removal of the combustion process from the living space. Furnaces can be placed in a garage or even in a small out-building, and hot water can be piped back into the living space. Gas-fired condensing heat pumps may also provide a means of keeping fossil fuel use external to the house.

One case has also come to this author's attention of a chemically susceptible person who experienced severely debilitating symptoms as a result of exposure to gas fumes from a gas furnace and hot water heater. The location of the building precluded placing a gas boiler external to the house, because of vandalism problems. Instead a small tightly-sealed and well-insulated room was constructed around the furnace. Direct ventilation to and from the outside was introduced into that room, effectively making it 'external' to the remainder of the living space. At last report this solution has been successful.

1.7.8 Changes in Building Design and Construction Practices

So far there are very few references in the indoor air pollution literature which offer practical advice on retrofitting old houses or building new houses in order to provide an atmosphere with lower than normal indoor air pollution.

Section 2 "Low-Pollution Design and Construction" reviews problems and solutions with specific reference to the author's 'Sunnyhill Research Centre', an experimental low-pollution building northeast of Toronto. Advice is given as to the applicability of each technique to conventional housing in Canada.

The reader is referred as well to Zamm (1980) for an introduction to problems caused by present construction methods and some advice as to alternative materials and methods. Previous papers by this author (Small 1978, 1979) also summarize the basic principles of low-pollution design and ways of helping householders apply them in their own circumstances. Most of the points presented therein are included in Section 2 following.

1.7.9 **Changes in Building Maintenance Practices**

Description:

Hollowell & Miksch (1981, p.7) suggest that episodic contaminant generation from building maintenance products can be reduced by offsetting product use from the workday period (i.e. clean at night and on weekends).

In residential situations, examples include painting or doing other major redecorating only during times of the year when occupants can either move out temporarily or open the home for full natural ventilation. Some allergically sensitive persons hire others to dust and vacuum, and stay away during the cleaning and for several hours afterward.

Zamm (1980) suggests a variety of simple cleaners (including baking soda) to replace the wide collection of volatile and poisonous household cleaning products now commonly in use.

Although very little has been written in this area, it is clear that there is much scope for reduction of pollutant levels by reducing the heavy reliance on chemical products for cleaning. Alternative products may be required for some applications (e.g. safer waxing compounds) but in general alternatives have existed for many decades and were in general practice prior to development of newer alternatives. Significant savings in maintenance costs could accrue, because in many cases expensive products are being used where a simple damp cloth would suffice.

One area that requires a great deal of attention is the development of non-chemical means of pest control, to reduce the overall exposure of humans to pesticide chemicals indoors.

1.7.10 **Air Filtration**

Description:

Filtration and/or scrubbing of intake and recirculated air can remove airborne particles and gaseous contaminants (Hollowell, 1981. p. 9). In general filters which take out gaseous contaminants are separated from those designed to trap particulates.

Particulates can be removed by impinging on an adhesive surface (e.g. low-efficiency fiberglass furnace filters), by being caught between fibers of varying diameters (e.g. medium to high- efficiency paper or fabric filters) or by being charged and attracted to surfaces adjacent to the air stream (e.g. electrostatic filters) (Raab, 1982).

Gases can be removed by filtration through a bed of activated carbon (charcoal) or through chemisorbant materials that first capture pollutants on a surface and then combine with them chemically through oxidation.

Although there is an extensive industrial filtration literature, there is far less written on the use of filters in homes to remove pollutant gases. A full review of filtration is beyond the scope of this present review. Comments by this author on filtration are confined primarily to Section 1.2 "Low-Pollution Design and Construction".

Discussion:

Doris, Harper & Morris (1972, p. 1) note that fungi can colonize charcoal granules used for removing hydrocarbon contaminants from the atmosphere. Low measurements of fungal spore contamination in nuclear submarines would indicate, however, that a charcoal air recirculation system successfully reduced rather than increased the airborne spore population.

Jonassen (1981b, 1981d, and 1982) discusses the pros and cons of air filtration for removal of radon and radon daughter products. Airborne radon daughters may appear attached to aerosol particles, or as unattached molecular-sized clusters. Mechanical (particulate) filtration will decrease the attached radon daughter concentrations, but will also remove other aerosols from the air. Radon itself is not captured, since it is a gas. There is then an increase of unattached polonium isotope with a high dose efficiency which compensates for the reduction in attached daughter products this. The overall radiological dose to the bronchial tract remains approximately constant and under certain circumstances may even increase. Preliminary results with deliberate introduction of additional condensation nuclei in the air during filtration indicate that the unattached polonium isotope concentration and the total dose can be reduced significantly. Jonassen notes that charcoal filtration, on the other hand, will capture radon itself and bypass this problem.

Miles et al (1980) also measured the effectiveness of filtration devices on radon concentrations, and concluded that an electrostatic precipitator in a room in which air was circulated by air-mixing fans was effective in removing both attached and unattached radon daughters from the air, the latter partly by deposition on room surfaces and on the blades of the fans. In their experiments no significant changes in radon daughter concentrations were found during successive use of a humidifier, a dehumidifier, and a carbon filter.

Raab (1982) reviewed the present problems and opportunities in residential forced air filtration. He concludes that the commonly-used 'throwaway' furnace filters are 'primitive technology of very low efficiency'. He notes that pleated fabric filters are now available in sizes suitable for residential furnaces, and could provide medium-efficiency filtration with beneficial effects on health, maintenance requirements (including duct cleaning) and energy consumption.

Raab describes the dubious advantage of the thin throwaway filters as being their ability to pass air even when heavily laden with dirt - in a sense 'forgiving' the common lack of maintenance on the part of many of Canada's homeowners. Often furnace fan assemblies are caked with dirt and heating cycles have become longer to accommodate the decreased air flow to the home.

Rabb recommends the use of higher-efficiency particulate filters combined with a differential pressure monitor which would activate a signal when the filter becomes clogged. This approach would be an effective way of reducing particulate concentrations in indoor air.

The use of filtration of either particulate kind or gaseous kind for persons who are generally chemically susceptible can present problems. In general, persons allergic to inhalants such as dust and pollens may benefit from high-efficiency particulate filtration. Some, however, have also become sensitive to chemical exposures. Ozone from electrostatic precipitators and binding chemicals from high-efficiency filters may precipitate symptoms in such persons despite the reduction in particles. The pros and cons of filtration for the highly susceptible are discussed further in Section 1.2.

1.7.11 Use of Sealants (e.g paints, veneer, or plastic barrier)

Description:

Emissions of potentially harmful pollutants can be reduced in some cases by coating high-emission materials with sealants (Hollowell, 1981, p. 8).

Applicability:

Jonassen (1981b) comments that diffusion-barriers and sealants can be applied to surfaces emitting radon gas (e.g. basement concrete walls) to control the outgassing of radon. Culot et al (1978) reported on a number of buildings in Grand Junction, Colorado, in which uranium mill tailings had been used to level under the basement slab or to backfill outside the footings. A multi-layered epoxy barrier painted onto the inside of the concrete basement wall and on the floor was reported to be practical and effective in reducing radon influx into the buildings, in combination with other methods such as sealing cracks.

Discussion:

Section 1.5.11 discusses the problems presented by paints and sealers to the hypersusceptible population. While formaldehyde or radon may present a hazard from a wall surface, for some individuals the introduction of an epoxy sealer to stop the first pollutant could just be trading one problem for another. Some persons have used paints successfully with the addition of about .5 kg of sodium bicarbonate per gallon, mixed well, but this has not proved to be universally acceptable nor compatible with all forms of paint.

The use of 'skinning' materials has provided some interesting new composite boards which may provide a partial solution to the gassing-off properties of particleboard and polystyrene foam insulations. The factory-made combination of a plastic laminate skin on a particle-board base for kitchen cupboards could reduce kitchen formaldehyde problems considerably, particularly if care is taken to cover all exposed particleboard edges during construction. New insulation products involving aluminum-foil covered boards are an improvement over exposed foam boards, but again there is still a potential for release of pollutants unless care is taken to seal exposed edges.

1.7.12 Adjustment of Product Formulation

Modification of the manufacturing process or product constituents for building materials, furnishings, etc., could achieve a product with lower pollutant emissions. (Hollowell, 1981, p. 9) The European example of low-formaldehyde particleboard is a good example of this kind of solution.

While there may be other examples of industrial processes which do accomplish this for existing products, none were found during review of the indoor air pollution literature and an extended search was beyond the scope of this study.

1.7.13 Treatment of Final Product

Some references suggested that free chemical outgassing components could be baked, aired out or otherwise treated at the factory by adding one or two simple stages to the production process.

1.7.14 Ventilation of Specific Sources

Description:

'Spot' or 'task' ventilation using exhaust fans, e.g. in kitchens and bathrooms, has been suggested as a means of removing pollutants close to the source (Hollowell, 1981, p. 9).

Applicability:

Cain, Leaderer et al (1981) suggest that segregation of smokers into small areas with high ventilation would suffice to eliminate strong discomfort to nonsmoking occupants and to minimize a severe energy penalty in ventilating areas for general occupancy. Their experiments showed that as soon as a person lights a single cigarette in a normally ventilated room of small to moderate size, both odour magnitude and concentration of particulate matter tend to climb to unacceptable levels. Successive cigarettes drive the levels up farther and only an hour or more of continued ventilation after heavy smoking may suffice to bring the levels down to an acceptable point.

ASHRAE standard 62-81 recommends ventilation of 35 cfm per occupant for smoking occupancy. Leaderer et al (1981) found that compliance with (U.S.) criteria for total suspended particulates would require ventilation at a rate four times higher than that specified in the ASHRAE standard. The energy penalty involved in achieving that level of general ventilation makes ventilation of a smaller 'smokers-only' area an attractive option.

The National Building Code of Canada (Associate Committee on the National Building Code, 1977) specifies in sections 3.6.3.1 and 9.33.2.4:

> "Air contaminants released within buildings shall be removed insofar as possible at their points of origin and shall not be permitted to accumulate in unsafe concentrations."

This would appear to be in support of the 'spot' or 'task' venting approach to minimizing indoor pollution from tobacco smoke and other sources.

Traynor, Apte, Dillworth et al (1981) demonstrated that spot ventilation of a gas stove (by means of a standard range hood) was more effective in reducing NO2 concentrations than was increased general ventilation of a dwelling. They recommend that gas stoves should not be used in very tight structures unless some type of pollutant removal strategy, such as spot ventilation, is incorporated.

Advantages:

'Spot' ventilation need only be used while pollutants are being emitted (e.g. during cooking) and removes pollutants before they migrate throughout the building (Hollowell, 1981, p. 9).

Discussion:

See also Section 2 "Low-Pollution Design and Construction".

1.7.15 Human Factor Control

It is surprising how little mention is given in the indoor air pollution literature to the possibility of 'human factor control', that is voluntary and deliberate reduction of polluting activities by an informed public. General reduction of smoking has rarely been suggested despite the positive public health implications. Individuals can also exercise considerable choice in the purchase of household products and building materials.

As socially unacceptable as it may sound, greater co-operation by individuals in controlling indoor pollution at the source may be a necessary part of the overall solution.

1.7.16 Warning Devices & Controls

Use of air quality monitoring devices and feedback control systems have been suggested to control mechanical ventilation (Hollowell, 1981, p. 9) While there is little other mention of this in the literature, the applications for the world's growing capability in microcomputer technology seems an obvious development to expect in the field of indoor air pollution and environmental control.

1.7.17 Factors Reducing Indoor Air Pollution: Summary Table

Section/ Factor	Summary
1.7.1 Increased Ventilation	Increasing ventilation is effective in diluting indoor pollutants, but can increase energy costs. New heat exchangers may provide a means of keeping indoor air clean at less cost.
1.7.2 Decreased Ventilation	Occasionally reduction of general ventilation may be advisable in order to avoid infiltration of concentrated outdoor pollution (e.g. wood smoke).
1.7.3 Adsorption on Interior Surfaces	A number of air contaminants either react with or are absorbed by various surfaces within a room. This can help reduce peak concentrations but absorbers may later become emitters.
1.7.4 Gassing-Out Time	Some materials or finishings can be left to 'gas out' for a period prior to use, thus reducing pollutant exposure to building occupants.
1.7.5 Low-Emission Materials	Materials, appliances, mechanical systems, etc. can be selected with lower pollution emission in mind.
1.7.6 Source Removal	Removing the source is most often effective, but can be expensive (e.g. UFFI removal). There can be difficulties in finding replacement materials that will not present further problems for persons who may already be generally chemically susceptible.
1.7.7 Modified Combustion Processes	Maintenance, adjustment, or redesign of indoor combustion sources may reduce emissions and/or ensure that emissions are properly vented to the outside.
1.7.8 Changes in Design	Ultimately a number of improved design and construction practices can help to reduce indoor pollution.
1.7.9 Changes in Maintenance Practices	There is much scope for reduction of pollutant levels by reducing heavy reliance on volatile chemical products, e.g. for cleaning.

1.7.17 Factors Reducing Indoor Air Pollution: Summary Table

1.7.10 Air Filtration	Pollutants indoors can be reduced with gaseous and particulate contaminant filters. Practical problems of upkeep and annual cost must be solved. Those who need filtration most are last able to tolerate various filtration media.
1.7.11 Use of Sealants	Some pollutant emissions can be curbed by sealing the offending surface (e.g. with a paint or with an impervious material as a barrier).
1.7.12 Adjustment of Product Formulation	Modifications may be possible in the constituents or in the manufacturing process of building materials and furnishings that pollute.
1.7.13 Treatment of Final Product	Additional treatment processes at the factory might reduce outgassing in the home.
1.7.14 Ventilation at the Source	Removing pollutants at the source is more effective for good air quality and better for energy conservation.
1.7.15 Human Factor Control	Voluntary and deliberate reduction of polluting activities by an informed public may be one part of the solution. Individuals can exercise some choice.
1.7.16 Warning Devices & Controls	Use of air quality monitoring devices and feedback systems to control mechanical ventilation may help to maintain better quality indoor air.

1.8 Summary and Interpretation of Literature Review

The following is a brief summary and interpretation of key findings reported in the literature review. Opinions expressed are those of this author only and do not necessarily reflect the view of the Canada Mortgage and Housing Corporation.

1) Many materials and conditions which contribute significantly to indoor air pollution are known to be present in Canadian homes.

The literature review preceding establishes that there are many materials and conditions known to be present in Canadian homes, which contribute significantly to indoor air pollution. Since the research and measurements cited were performed primarily in the United States and Europe, the number of Canadian homes in which air pollution levels present a major problem is not known. It is likely, however, that in most locations indoor air is more polluted than outdoor air.

Typical indoor air in most buildings is like a thin 'chemical soup'. Most dwellings contain many air contaminants at relatively low concentrations, below present industrial and outdoor exposure limits. These levels of exposure can pose a health problem at least for certain high-risk groups. The long-term risk to the general population is unknown.

Some dwellings have levels of indoor pollution which exceed present outdoor and industrial air quality standards and present known health risks. Pollutants posing the greatest hazards and requiring the most immediate attention include:

a) carbon monoxide
b) nitrogen dioxide
c) formaldehyde
d) radon gas

Poorly ventilated or badly maintained combustion equipment (e.g. stoves, heaters, and furnaces) can cause high pollutant levels and pose a serious health risk. In some cases (e.g. blocked chimneys on gas furnaces) death can result.

The trend to greater use of synthetic and plastic materials, glues, composition boards, sealing compounds, and a greater number of additives in paints, sealers and in the production of household fabrics and furnishings has contributed to a higher likelihood of increased indoor air pollution levels. Modern Canadian households are also veritable chemical arsenals of cleaning, deodorizing and pesticiding products, all of which contribute in minute amounts to the total indoor air quality problem.

Many Canadians are now experiencing chronic adverse health effects apparently due to indoor air pollution. Limited information on the health effects of specific building materials (e.g. UFFI and particle board) and on the effects of common pollutant levels on susceptible populations indicates that the number affected is at least in the thousands and could be substantially more. The risk to the majority of Canadians may be significant but has not yet been determined.

The continued introduction of energy conservation measures such as tightening houses and reducing ventilation rates will increase indoor air pollution and will increase risk to the health of a large number of Canadians, unless measures are taken at the same time to ensure clean indoor air.

2) Some people are more susceptible to air pollution than others, and even individual susceptibility varies over time.

It has been known for some time that air pollution, indoors or out, can cause or aggravate disease in at least a small proportion of the population. It presents the greatest risk for select populations, including the very young, the elderly, persons with respiratory and cardiovascular disease, persons with nutritional deficits, smokers, persons with active allergic disease or allergic histories, and persons who are already chemically susceptible but who may or may not belong to the risk groups mentioned.

The magnitude of the risk varies with the pollutant, the exposure, and the individual. Most of the conventional risk categories above are in theory countable since they are identified in statistics for other purposes, and in total they represent a sizeable proportion of Canada's population (greater than a third). The group of people who are already highly susceptible to indoor chemical exposures appears to span all age, social, and health categories and their total numbers will likely remain unknown until health surveys incorporate this category specifically.

Only recently it has also been reported that exposure to a number of chemicals, including some found in indoor air, has in some cases caused people who had no apparent risk factors to become highly susceptible to even minute exposures of pollutants from all sources, indoors and out, in air, water and food. Several factors in our sociey, including pollution exposure, dietary habits, and stress, appear to be creating a larger population of these susceptible people.

It is also important to understand that everyone's ability to adapt to pollution without experiencing adverse symptoms or health damage may vary over time. We all may be more susceptible when very young, very old, during periods of inadequate nutrition, during periods where total stress is high, or while fighting viral infections or other diseases. Indoor air pollution is therefore a total population problem, and not just that of a minority.

No provisions exist in Canada for the housing needs of those who have developed severe sensitivities to pollutants common in conventional housing. Many buildings both public and private are dangerous to the health of persons in this group and are effectively inaccessible to them. At any one time there are very few dwellings on the housing or rental market, including new and old buildings, that are suitable for persons with severe susceptibility.

New housing represents in general a far greater hazard to the chemically susceptible population than does older housing. Tightening of houses, reduction of ventilation, and the introduction of new and more volatile materials are prime contributors to increased hazards to the chemically susceptible population. The question of how housing standards can accommodate the apparently wide variation in susceptibility to indoor air pollution has not been addressed in the literature.

3) Smoking remains a major source of indoor pollution.

Longstanding medical evidence on the effects of tobacco smoking indicates that despite many other potential problem sources, smoking is a major and significant source of indoor air pollution.

Recent studies of ventilation requirements for tobacco smoking indicate that smoking indoors is totally incompatible with good health and clean indoor air. Tobacco smoking is just too efficient a pollution source to ventilate properly without large expenditures on equipment and energy.

If people must smoke, a price will be paid in health costs or in energy costs for ventilating, or both. As socially unacceptable as it may sound, the least energy penalty is paid if a small smoking area with local ventilation is provided within the home.

Widespread acceptance of smoking and of the health damage attributed to it has until now made it difficult to justify concern over the health problems caused by other sources of indoor air pollution. Now that more information is available on other sources and action is being taken on them (e.g. formaldehyde), tobacco smoking stands out more prominently as a problem that can no longer be accepted in its present form. More people appear to be aware now that there are significant adverse health effects of smoking both on the smoker and on others breathing sidestream pollutants from smoking. The social climate may be better now than before, for a gradual move to safer practices.

Because of the addictive nature of smoking, it is likely to continue on a large scale for years to come, despite its ill effects and despite campaigns to reduce smoking. If damage to both smokers and their close companions is to be minimized, however, better ventilation of smoke, as close as possible to the smoker, must be achieved.

Smokers and their non-smoking companions and families (passive smokers) must individually choose whether they wish to pay the price of smoking in increased health costs or in the increased energy cost of good ventilation. The idea of adapting housing to limited tobacco use (e.g. with spot ventilation of small smoking areas) has been suggested and could help to minimize both adverse health effects on non-smokers and energy costs of ventilation.

4) Some energy conserving measures aggravate indoor pollution problems.

Energy conservation measures are in part responsible for apparent recent increases in the incidence of indoor air pollution and the adverse health effects from it. Primary causes are:

- reduction of ventilation rates by tightening houses
- introduction of volatile materials affecting health
- poorly installed or maintained combustion equipment

Recent work reported in the literature indicates that increased attention is being paid at least by a small number of researchers to designing energy conserving measures that do not aggravate existing indoor pollution. These include:

- careful selection of materials to avoid pollution
- use of heat exchangers to allow sufficient ventilation without excessive energy loss

The present indoor air quality problem does not mean that energy conservation should be abandoned, but rather that the technology for achieving it must in some cases be redesigned to take both goals into account. To a large extent, the cost of providing relatively clean indoor air can be measured most directly in the energy cost of increased ventilation. This cost can be minimized by reducing pollutant sources within a dwelling or by venting pollutants right at the source (e.g. by a fume hood over a gas stove). As with energy conservation, providing clean air requires a whole technology of ideas that must be developed, tested, and put into general practice in order to become economical.

The magnitude of investment in energy, in buildings, and in health care in Canada is enormous. It is therefore important that energy, health, and pollution all be considered together so that actions in one area do not cause major problems in another. The cost of good research and analysis of the indoor air problem is minor compared to the social, legal and economic costs of ignoring it.

5) The full health, social, and economic costs of indoor air pollution have yet to be determined.

One of the most serious aspects of Canada's indoor air pollution problem is that there are major gaps in our knowledge of its effects.

Indoor air quality standards which fully account for long-term continuous exposures to complex mixtures of pollutants, each at relatively low levels, have not yet been developed. The literature on health effects of common indoor pollutants deals primarily with observation under other than residential situations. Many decisions on allowable levels of exposure to these same chemicals outdoors and in the workplace have been based on studies of the health effects of single chemicals, at relatively high levels of exposure, on relatively healthy animal or human subjects.

In the past, threshold values of chemical exposures have been used to indicate levels above which no significant problem is expected in the general population. In the more recent literature on indoor pollution this concept has been questioned, because of the wide individual variation in reaction and because of the unknown effects of multiple combinations of low-level pollutants.

Questions which have not yet been well addressed in the literature, particularly for Canada, include:

- What is the distribution of indoor air pollution (by pollutant and level) in Canadian housing?
- What is the distribution of overall pollution exposures among the Canadian population?
- How many people in Canada are adversely affected now by indoor air pollution?
- What are the possible medical effects of long-term low-level exposure to indoor air pollution?
- How many people in Canada are at high risk due to inherent susceptibility to pollution?
- How many people not now experiencing adverse effects can be expected to develop longer term effects?
- How can people with health problems due to pollution exposures be properly treated and rehabilitated?
- What are the social and economic costs of the effects of indoor air pollution?

In this author's opinion, the early warning signs indicate that indoor air pollution is already a major problem and has already had considerable impact on Canadian society, its individuals and its economy. Research must be undertaken now on many fronts in order to reduce the risk of creating even greater health, social and economic problems as a result of long-term exposure to air pollutants.

Any decisions made now that affect buildings in Canada must allow for considerable new knowledge on the effects of indoor air pollution coming to light over the next 10 years.

6) Acceptable levels of effects on health have not been defined.

With few exceptions the literature fails to discuss what level of effects on health should be considered acceptable to our society. That is, in a risk analysis, how many deaths, how many diseased and disabled persons, and what level of common discomfort must be accepted in exchange for affordable housing and reasonable energy conservation. It is clear that there will be some casualties and adverse health effects no matter what measures are taken to minimize the indoor air quality problem. Many of the health effects can only be predicted on a statistical basis (e.g. lung cancer from radon decay products).

The concept of providing housing that promotes good health is almost totally absent in the literature and in general design and construction practice. While heating and air conditioning studies do address human comfort issues in considerable detail, they fall short of a comprehensive approach to total building design and lifestyle planning that might help to foster better health for Canadians in the face of other modern stresses.

Indoor air pollution is only one factor among many that can adversely affect public health. Its relative importance as a cause of disease has not yet been established, although some researchers suggest that it could be far more significant than is commonly believed. In the long run the indoor air pollution problem should be evaluated in the widest context of society's health, social, and economic goals.

Keyword Summary of Conclusions

1) Many materials and conditions which contribute significantly to indoor air pollution are known to be present in Canadian homes.

2) Some people are more susceptible to air pollution than others, and even individual susceptibility varies over time.

3) Smoking remains a major source of indoor air pollution.

4) Some energy conserving measures aggravate indoor pollution problems.

5) The full health, social, and economic costs of indoor air pollution have yet to be determined.

6) Acceptable levels of effects on health from indoor air pollution have not been defined.

PART 2: LOW-POLLUTION DESIGN AND CONSTRUCTION

Indoor air quality is emerging as a new and important factor, like energy conservation, that will affect the design of new housing and home renovation in Canada. Low-pollution design is presently at a point similar to the earliest stages of concern about energy conservation in homes. There are yet only a few examples where principles of low-pollution design and construction have been introduced and evaluated, and a great deal of research is needed before a consensus can be reached on the most appropriate design features.

The author is presently constructing a 560 sq. m. (6000 sq. ft.) experimental building, known as the 'Sunnyhill Low-Pollution Research Centre', near Goodwood, Ontario, about 45 km. northeast of Toronto, Canada. The design principles and construction techniques used in this building are described in this section.

The 'Sunnyhill' example is designed for the lowest possible indoor air pollution. The building therefore represents one end of a full spectrum of possible indoor air quality standards and building methods.

The applicability of design and construction methods used at Sunnyhill to conventional housing in Canada is also discussed.

Sub-Index of Part 2

2.1 The Sunnyhill Example 165

  2.1.1 Background and Problem Addressed 165
  2.1.2 Design Principles 168

    a) The Physics of Indoor Air Pollution 168
    b) General Methods for Reducing Indoor Air Pollution Exposure 169
    c) How the General Methods are Applied in the Sunnyhill Example 170

  2.1.3 Materials and Testing Methods 174
  2.1.4 Design of Features and Systems 181

    a) Location 182
    b) Airtight Construction Using Cavity Wall 183
    c) Steel Framing and Concrete Floors 184
    d) Interior Framing Separated from Vapour Barrier on Outside Wall 185
    e) Deliberate Venting Through Multiple Inlets 186
    f) Tempering and Filtration Of Intake Air 187
    g) Recirculation of Interior Air With Filters 188

(continued)

        h) Passive Solar Design 189
        i) Hot Water Electric Heating Source and Potential for Heat Pump and Solar Heat 190
        j) Low Temperature Radiant Heat in Ceiling 191
        k) Central Exhaust System 192
        l) Lighting Fixtures Embedded in Ceiling 193
        m) Generous Provision of Cupboards, Some Vented 194
        n) Layout For Separation of Activities 195
        o) Use of 'Bedroom Sanctuary' Concept 196
        p) Central Vacuum Cleaner with Exterior Motor 197
        q) Bare Floors Without Wall-to-wall Carpeting 198
        r) Relatively Bare Furnishings 199
        s) Unpainted Plaster Walls 199
        t) House Rules 200

    2.1.5 Construction Techniques & Supervision 201

        a) Cavity wall construction 201
        b) Attachment of Interior Insulation 204
        c) Construction Supervision 207
        d) Effect of On-Site Pollution on Construction Personnel 210

    2.1.6 Effectiveness of Design 212
    2.1.7 Ongoing Monitoring and Research 214

        a) Monitoring of indoor and outdoor pollutants 214
        b) Development of automatic control systems 215
        c) Effectiveness of design for diagnosis and rehabilitation of persons with chemical susceptibilities 215
        d) Testing of materials in the low-pollution environment 216

2.2 Application to Current Construction Practice 217

    2.2.1 Evidence of Need 217
    2.2.2 Problem Materials and Design 217
    2.2.3 Energy Conservation 220

        a) Addition of insulation 220
        b) Addition of caulking and other sealants 220
        c) Super-sealing the building envelope 220
        d) Installation of air solar heating 221

    2.2.4 Adaptable Techniques 221
    2.2.5 Cost Implications 222

2.1 THE 'SUNNYHILL' EXAMPLE

2.1.1 Background and Problem Addressed

The idea of creating a special Low-Pollution Research Centre grew directly from the need of this author and his family for cleaner air for medical reasons. Diagnosed in 1976 as being 'chemically susceptible', our requirements included a general lowering of our overall pollution load during as great a proportion of each day as possible, for an extended period. Readers are referred to Section 1.3 for a review of chemical susceptibility, and to two previous publications (Small and Small, 1980, and Small, 1982a) for further personal and medical background information.

It had also become apparent to this author that there was an identifiable and growing population of chemically susceptible persons in Ontario, yet there were neither appropriate housing nor appropriate clinical testing facilities for this population. Nor did there exist a well-defined and well-documented body of knowledge concerning principles of low-pollution design and construction.

The five primary functions to be provided by the Sunnyhill Low-Pollution Research Centre became:

1) housing for this author and his family, with the lowest practical indoor air pollution levels,

2) business space for this author's firm and associated computer equipment, also designed for the lowest practical indoor air pollution levels,

3) clinical space (designed for the lowest possible indoor air pollution) for use by physicians and other researchers to experiment with treatment and rehabilitation of persons suffering from environmentally-related disease,

4) educational space for:

    - conducting seminars, lectures and workshops in a low-pollution environment, to further transfer of knowledge on the effects of environment and health,

    - conducting experimental school classes and assessing the effects of low-pollution environments on learning, especially in young children,

    - housing computer equipment for creation and operation of data banks on low-pollution design and environmental medicine,

5) prototypes of design and construction methods for residential, commercial and clinical low-pollution environments, applicable to specialized buildings and to general construction.

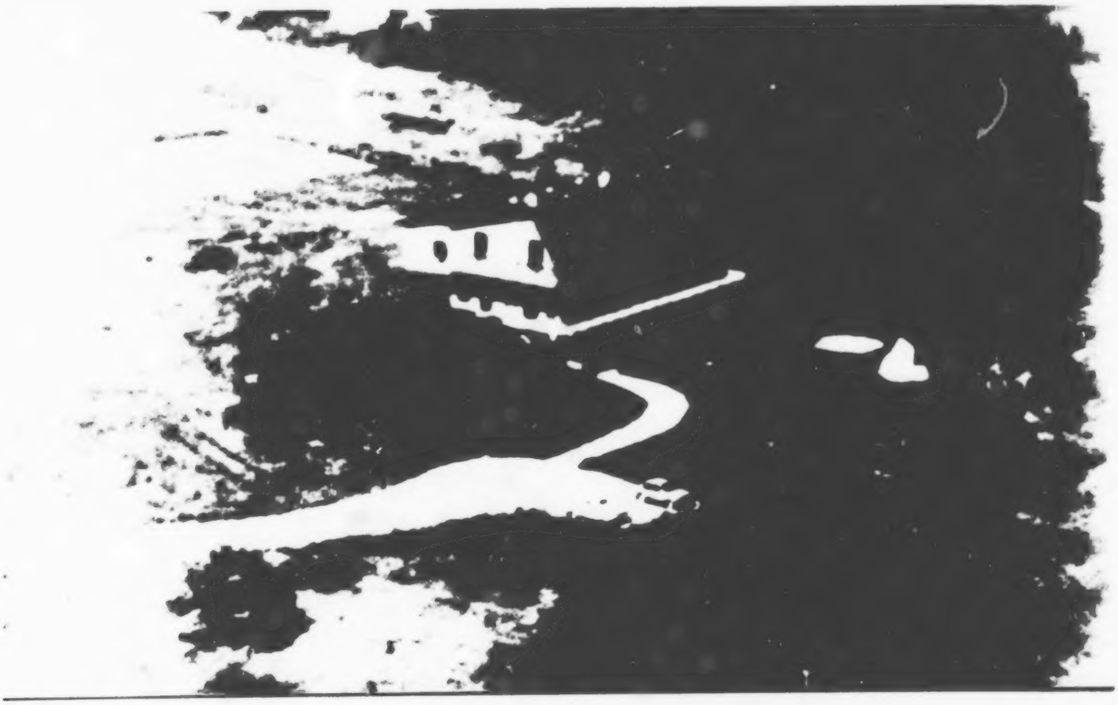

Figure 9: Sunnyhill Low-Pollution Research Centre (aerial view)

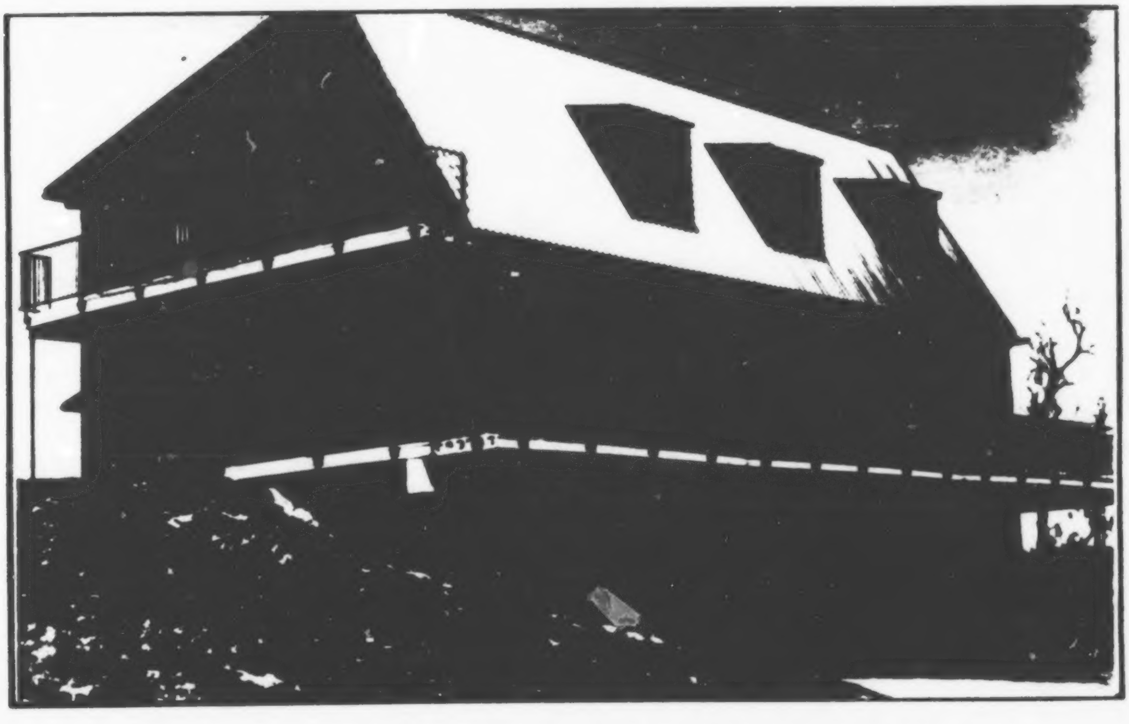

Figure 10: Sunnyhill Low-Pollution Centre (taken from the southwest)

GROUND FLOOR FUNCTIONS:

- o SEMINARS/LECTURES
- o RECREATION/GYM
- o EDUCATION EXPERIMENTS
- o UTILITIES/LAUNDRY
- o STORAGE

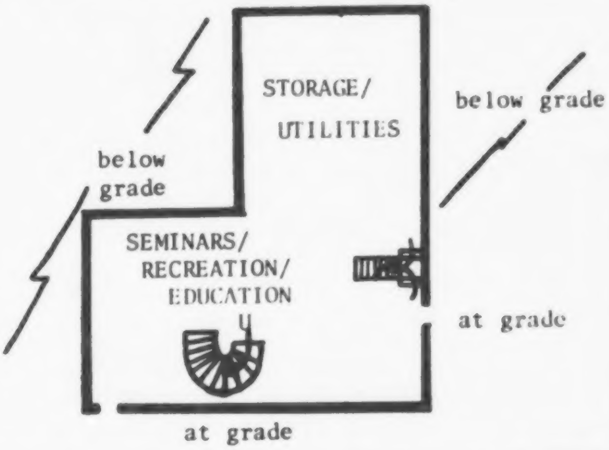
STORAGE/
UTILITIES
below grade
below
grade
SEMINARS/
RECREATION/
EDUCATION
U
at grade
at grade

Figure 11: Sunnyhill Low-Pollution Centre - Ground Floor Functional Areas

FIRST FLOOR FUNCTIONS:

- o AUTHOR'S RESIDENCE
- o KITCHEN/DINING/SITTING
- o MEETINGS & BRIEFINGS

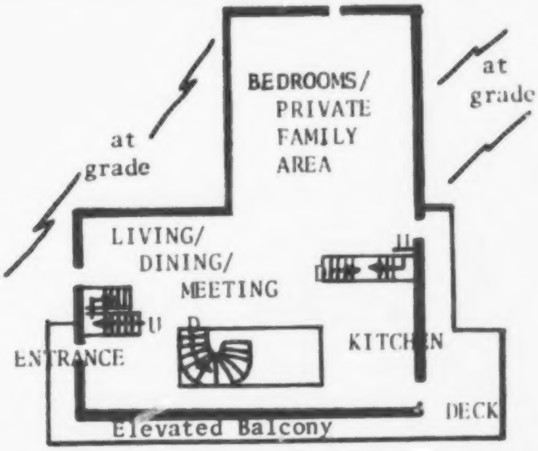
BEDROOMS/
PRIVATE
FAMILY
AREA
at
grade
at
grade
LIVING/
DINING/
MEETING
U
U
D
ENTRANCE
KITCHEN
DECK
Elevated Balcony

Figure 12: Sunnyhill Low-Pollution Centre - First Floor Functional Areas

SECOND FLOOR FUNCTIONS:

- o BUSINESS OFFICES
- o LIBRARY & COMPUTER
- o CLINICAL AREAS:
  - - BEDROOMS
  - - ACTIVITY AREA
  - - TESTING AREA

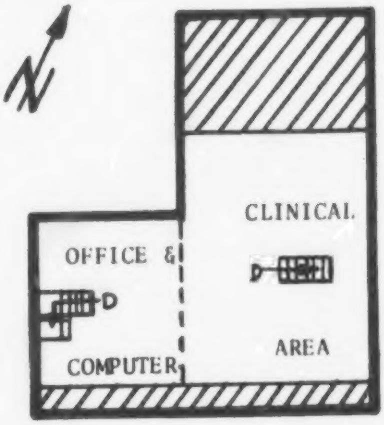
N
CLINICAL
AREA
OFFICE &
COMPUTER
D
D

Figure 13: Sunnyhill Low-Pollution Centre - Second Floor Functional Areas

Sunnyhill is a privately funded project owned by the author and operated by Bruce M. Small and Associates Limited. Detailed design work began in 1977 and construction started in June 1978. The building is not fully completed at the time of writing because of financing difficulties. The descriptions of design and construction methods in the sections following therefore include some interior features that have not yet been manufactured, installed, or tested.

Figures 9 and 10 illustrate the building exterior at its present stage of completion, and Figures 11, 12 and 12 show the general floor plans which outline the different functional areas described. The final floor plans may differ somewhat in detail but all main functional areas will be included.

2.1.2 Design Principles

a) The Physics of Indoor Air Pollution

The principles of low-pollution design can be derived fundamentally from the properties of open systems. A 'system' can be defined as any arbitrary volume, such as an identifiable object or collection of objects. Physics theory and experiment dictate that all such systems are 'open' systems - that is, they tend to exchange energy and material with their environment. No totally closed systems have yet been discovered.

In building design today, the fact that the components, furnishings and occupants within a building are all open systems has been largely ignored. In practical building terms, this means that materials within a building tend to gas off or shed tiny particles, which then mix with the interior air. Each is thus a potential source of indoor air pollution. Many building materials and furnishings can also absorb gases or become coated with gases or particles from other sources, thereby acting at least part of the time as 'sinks' of air pollution.

Living systems must not only be open systems, but must exchange very specific amounts and types of energy and materials with their surroundings in order to maintain life and grow (Small, 1975). People within a building exchange air and energy with the indoor environment, and will absorb both needed gases and air contaminants. If the materials and energy they take in are not entirely appropriate, they will not thrive.

People also breathe out many compounds that are considered to be air pollutants. The total building in turn exchanges energy and materials with its environment. If the level of indoor contaminants is to be kept low in order that the occupants may thrive, there must be a continual flushing of unwanted materials to the exterior and a continual intake of needed materials.

Many energy conservation measures have been introduced in an attempt to make buildings systems more 'closed' as far as energy transfer is concerned. Some of these measures have altered the necessary flow of clean air and flushing out of indoor pollutants, and early designs largely ignored the fact that people and materials inside were still open systems that emitted pollutants into indoor air. Refinements such as air-to-air heat exchangers have helped to re-establish the proper air flow while still minimizing the energy loss.

The outdoor environment in turn also contains atmospheric pollutants, and some of these contaminants will be taken into a building, and contribute to indoor pollution levels. Because there are indoor sources as well as outdoor sources, pollution levels inside tend in general to be greater than those outside.

b) General Methods for Reducing Indoor Pollutant Exposure

A number of general methods for reducing the exposure of people to indoor air pollution can be derived from the discussion above. These can be applied in a wide variety of ways in each individual building. Subsequent sections will indicate how they have been applied in the Sunnyhill example.

1) Flush pollutants to the exterior
   (e.g. increase general ventilation or add special vents above pollution sources, such as a gas stove)

2) Exteriorize the pollution source
   (e.g. place a well-sealed air and vapour barrier on the interior side of the building insulation, allowing gas-off products from the insulation to migrate outside but not inside)

3) Scrub pollutants from the air within the building
   (e.g. add special filters in the air circulation system that will remove pollutant gases and particles from the indoor air)

4) Substitute low gas-off materials or systems for high gas-off ones, and/or reduce the need for high gas-off products
   (e.g. change furnishings or change the heating system, or reduce energy needs and therefore pollution from the heating system)

5) Seal a pollution source to reduce emissions
   (e.g. cover high gas-off materials such as particle-board with an impermeable skin such as a hard plastic laminate)

6) Treat a pollution source to reduce emissions
   (e.g. bake a paint with infrared radiation or wash a furniture fabric to reduce free volatile chemicals)

7) Separate people from pollution source
(e.g. remove offending materials from the home, or remove sensitized occupants to more suitable housing)

8) Isolate affected individuals in special filtered rooms or by personal air filtration units
(e.g. clean out one room for a sensitized person or provide a breathing mask that filters out contaminants)

General advantages and disadvantages of each of the above methods are outlined briefly in Figure 14.

c) How the General Methods are Applied in the Sunnyhill Example

1) **Flushing pollutants to the exterior:**

- general low-level exhaust of air in each room through ceiling and vents; exhaust system is powered by two 1000 cfm vent fans mounted on the north roof slope, and exhaust heat is salvaged through local and central heat exchangers
- exhaust of ceiling space air contaminated by outgassing of light and other electrical fixtures
- specific venting of kitchen appliances, freezer and refrigerator motors, bathroom and other high humidity areas, home and office electronic equipment (television, radio, computer, typewriter, etc.), certain cupboards and storage areas, and specialized handicap appliances such as reading boxes
- central vacuum system for cleaning, with motor and exhaust mounted on the outside of the building
- openable windows in all above-ground rooms, for direct venting
- exterior wall vents in all rooms for filtered intake air

2) **Exteriorizing of pollutants:**

- use of cavity wall construction, with one layer of insulation exterior to a structural block wall, behind brick veneer and vented to the outside; block wall is sealed with cement parging to provide a complete interior air barrier. This creates an 'airtight' wall that allows deliberate venting and air control rather than uncontrolled infiltration and flushing of gas-off products from insulation into living spaces
- venting of roof insulation by providing a cavity beneath the metal roof surface; there is also a completely sealed vapour and air barrier beneath the roof insulation.

COMPARISON OF METHODS FOR REDUCING INDOOR AIR POLLUTION

Method	Advantages	Disadvantages
1. FLUSH POLLUTANT FROM BUILDING	- need not alter sources - often only moderately expensive	- lose energy - affected individuals still exposed to low levels - polluted outside air contaminates intake
2. EXTERIORIZE POLLUTANT	- need not alter sources - reduces air infiltration and energy loss - reduces air exfiltration and condensation	- barriers not perfect - seal may deteriorate
3. SCRUB INDOOR AIR	- need not alter sources - reduces ventilation needs and saves energy	- expensive - affected individuals still exposed to low levels
4. SUBSTITUTE MATERIALS/SYSTEMS	- affected individuals no longer exposed - reduces ventilation needs and saves energy	- sometimes expensive - substitutes often difficult to obtain
5. SEAL POLLUTANT	- reduces or eliminates exposure to affected persons - reduces ventilation needs and saves energy - often relatively inexpensive	- may introduce alternate pollutants - barriers not perfect - seal may deteriorate
6. TREAT POLLUTANT	- reduces or eliminates exposure to affected persons - reduces ventilation needs and saves energy	- may introduce alternate pollutants - not always possible - not always 100% effective
7. SEPARATE PEOPLE FROM POLLUTANT OR REMOVE POLLUTANT	- reduces or eliminates exposure to affected persons - can sometimes be inexpensive (eg. put volatiles in shed)	- not always possible - can sometimes be expensive (eg. remove UFFI)
8. ISOLATE AFFECTED PEOPLE	- reduces or eliminates exposure to affected persons - can be relatively inexpensive	- not always possible - creates social isolation and restricts affected persons

Figure 14: Comparison of General Methods for Reducing Indoor Air Pollution

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3) **Scrubbing of indoor air:**

- use of activated carbon and chemisorbant filters on intake air vents for filtering pollutants from incoming air
- use of same filter devices for recirculating room air
- use of portable air filtration devices with same media, for extra cleaning of individual rooms where necessary.

4) **Substitute materials or systems, and reducing need for high gas-off products:**

- all materials used are least-odour-producing alternatives where possible (see section 2.1.3 for details)
- energy conservative passive solar design reduces need for internal heat source
- all electric and solar heating is used rather than fossil fuel (see section 2.14 for details)
- low-temperature radiant heat ceiling panels are used rather than higher temperature heating sources (e.g. furnace heat exchanger)

5) **Sealing pollutant sources:**

- use of carefully sealed foil vapour barrier to reduce outgassing from interior insulation
- use of foil barrier where necessary to reduce outgassing from plastic piping and joint cement on waste plumbing and vacuum piping
- use of foil tape to cover exposed surfaces of plastic thermal break on window frames and where necessary to reduce outgassing of window sealant material in clinical rooms

6) **Treating pollution sources to reduce emissions:**

- washing of all fabrics to be used in interior furnishings or window shutters
- (subject to experiment) infrared and/or ultraviolet treatment of any painted interior surfaces to accelerate gassing off
- detergent washdown of metal components shipped covered with oil film, e.g. brick vents, galvanized intake ducting

7) **Separate people from pollutant sources:**

- lights and other electrical devices are sealed into ceiling and wall cavities and vented, so that pollutants do not enter indoor air
- extensive use is made of cupboards, some vented, to encourage storage of virtually all household items not used from day to day
- exterior storage (utility shed, exterior cupboards) of volatile workshop or garden materials
- strict no smoking and no perfumes policy

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8) Isolate affected individuals:

- each room is separable from others, with its own heat source, own intake vent and filtration unit; severely affected individuals can be isolated with extra air cleaning in areas with fewer pollutant sources
- bedroom sanctuary concept (sparsely furnished bedroom separate from dressing room where clothes are stored) guarantees a clear retreat for susceptible persons whenever necessary
- clinical wing is on the top floor, remote from the kitchen area and from the public seminar area; highly susceptible persons will be isolated whenever activities in other parts of the building could adversely affect them.

Two other design practices and one additional criterion were also important in the Sunnyhill example and are applicable particularly to design of other buildings which must cater to the needs of the chemically susceptible population.

9) Testing of All Materials Proposed for Use in the Building:

Where possible, all materials proposed for use in the building were tested for possible adverse effects on chemically susceptible people. A detailed description is given in Section 2.1.3 following.

10) Meticulous Attention to Detail:

Considerably more attention was paid to detail in design than would be applied to a conventional home. It was essential that there be a mininum of new problems arising during construction which would tempt subcontractors to introduce additional untested materials.

11) Flexibility to Change Building Interior:

Where possible, construction methods were used which would provide the utmost in flexibility to change the interior partitions, wiring, heating, and air handling systems over time, in response to developments in new technology and to any indoor air problems that might arise.

2.1.3 Materials and Testing Methods

All materials considered for use both in the building structure and the building interior were subject to testing by highly chemically sensitive persons.

In most cases testing was done by allowing the subject, usually the author or other family member, to inhale or 'sniff' fumes from a material sample at close range (3 cm. or less). Tests were performed at times when general symptoms of food and chemical susceptibility were low or absent, and while the subject was seated in a quiet air purified room with few furnishings.

Symptoms before and after exposure were noted. In the author's case, many building materials tended to cause immediate eye, nose and throat symptoms, including yawning, watering of the eyes, stuffiness, runny nose or sneezing, mild headache, and sinus pain. These symptoms often began within 30 seconds of the first exposure.

The relative strength of the reaction was gauged by the swiftness of symptom onset, the intensity of the symptoms, and the duration of symptoms before clearing. In the author's case the symptoms usually cleared within several minutes if the initial exposure was confined to a short 'sniff' and the material was subsequently taken out of the room.

Tests were usually confirmed by subsequent retesting on the same and other chemically susceptible subjects. If no immediate reactions are observed the test is also redone with longer exposures, e.g. by having a material sample placed in the bedroom or right next to a person while sleeping for 6-8 hours.

For practical and economic reasons, testing was not done in either a single or double-blind manner. Some testing was also done in a very informal manner at othe construction sites, whenever new materials were found exposed. By 1977 when design of the building began, the author and his family were sufficiently familiar with chemical susceptibility reactions that in most instances, genuine reactions to materials could be easily distinguished in nature from spontaneous symptoms from other causes.

Not all chemically sensitive subjects get either immediate or clearly defined reactions to materials to which they are sensitive. In the author's case testing was aided by three factors:

- having a tendency to react immediately and acutely upon exposure
- being at a stage in rehabilitation and treatment in which general signs and symptoms of food and chemical susceptibility were not present continually.
- having prepared a relatively chemically-clean test room.

At the stage in which chemically sensitive persons most desperately need clean housing, many are experiencing chronic, almost constant symptoms in various parts of the body, and have delayed reactions that are easily confused with responses to other environmental factors. Few have been able to provide pollution-free surroundings for testing. In such cases blind and double-blind challenges performed by a physician under rigorously prepared low-pollution surroundings would be desirable before making final decisions on appropriate building materials.

It is important that chemically susceptible persons not undertake such testing without the advice of a physician familiar with the effects of low-level chemical exposures. Exposures under such testing should not exceed the same order of magnitude of exposure as a person would encounter if the material had been installed in reasonable quantities in a home. Persons with extreme reactions such as asthma or cardiac arrhythmia should never be tested for such exposures except under rigorously controlled and medically supervised conditions.

Figure 15 describes how decisions were made based on the test reactions. For further description of testing methods, readers are referred to "Chemical Susceptibility and Urea-Formaldedhyde Insulation" (Small, 1982, pp. 28-32).

Figure 16 following lists the various building materials tested for the Sunnyhill project, along with conclusions reached. Readers please note that rejection of materials for the Sunnyhill application does not mean that they are generally unsuitable either for other specialized low-pollution housing or for conventional housing. Chemically susceptible persons are advised to test such materials carefully before considering their use. Further study is needed before it can be determined whether general use of the materials rejected for Sunnyhill would pose any health risk to others in conventional housing.

Figure 15: Interpretation of Test Reactions when Choosing Materials for Chemically Susceptible Persons

Response: Dose	No symptoms	Mild symptoms	Strong and immediate symptoms
1 short sniff 1 subject	potentially good material test longer exposure	potentially acceptable for some uses check longer exposure, other subjects	reject for all uses*; repeat to confirm
1 long sniff 1 subject	potentially good material test longer exposure and other subjects	potentially acceptable for some uses check longer exposure, other subjects	reject for all uses*; repeat to confirm
2 or more long sniffs, 1 subject	potentially good material check other subjects and repeat with longer exposure	potentially acceptable for some uses check other subjects and repeat	reject for all uses*; repeat to confirm
overnight exposure 1 subject	potentially good material check other subjects and repeat	potentially acceptable for some uses check other subjects and repeat	reject for all uses*; repeat to confirm
repeated exposures several subjects	acceptable material for some conditions; repeat under extreme conditions	acceptable for some uses if no other alternatives available; minimize quantities indoors	reject for all uses*
repeated exposures several subjects extreme conditions**	acceptable material	acceptable material for some uses if no alternatives available; minimize quantitites indoors	reject unless extreme conditions unlikely**

* if there is no reasonably economic alternative material for other than indoor applications, devise means of decreasing occupant exposure (e.g. sealing or venting) and retest; avoid indoor use if at all possible

** for example, some persons are not affected by concrete when dry, but react strongly to the odour of wet concrete. Concrete may be acceptable to such persons where exposed such as in basements, as long as proper drainage and dehumidification keeps it dry. Other materials may be acceptable at room temperature, but cause reactions when heated by sunlight.

Figure 15: Interpretation of Test Reactions when Choosing Materials for Chemically Susceptible Persons

Figure 16a: Testing Results on Principal Materials for Sunnyhill Application

Material	Test Results	Conclusions for Sunnyhill application only
softwoods (pine, cedar, spruce)	mild to strong reactions mild reactions even with 20-yr. old spruce	rejected unless no alternative; must be sealed if used
plywood	mild to strong reactions	rejected
particleboard	mild to strong reactions	rejected
tar-impregnated building sheathing	strong and immediate reactions	rejected
styrofoam sheathing	mild to strong reaction strong when heated	rejected
other sheathings	not tested	(cavity wall construction ultimately chosen)
bare structural steel	no response	accepted for interior use
portland cement	zero to mild response	accepted for indoor use
cement block	zero to mild response when well cured; strong response when fresh	accepted for structural use
clay bricks	no response	accepted for exterior use
mortar cement	mild to strong response decreasing with curing	accepted for brickwork and sealed structural blockwork but not for exposed interior use
portland/lime cement parging	no response	accepted for parging interior of block walls
rigid fiberglass cavity wall insulation	mild symptoms	accepted for exterior use or interior if well sealed
fiberglass batts	mild symptoms	accepted for roof insulation if well sealed, vented to exterior
styrofoam blue insulation	mild to strong reaction strong when heated	accepted for exterior use below grade only

Figure 16a: Testing Results on Principal Materials for Sunnyhill Application

Figure 16b: Testing Results on Materials for Sunnyhill (continued)

Material	Test Results	Conclusions for Sunnyhill application only
adhesives for attaching insulation	not tested	rejected in favour of mechanical fastening methods
other adhesives e.g for flooring	not tested	rejected from past experience
factory-coated rust paint for structural steel	mild to strong response	rejected in favour of bare structural steel
exterior rust paint	zero to mild response to now-unavailable mix of one brand of brown rust primer	accepted for finishing exterior steelwork
asphalt shingling	mild to strong reactions strong when hot	rejected in favour of enamelled steel
enamelled steel	zero to mild responses	accepted for use on roof
anodized aluminum	no response	accepted for interior and exterior use, window frames, etc.
CSL silicone caulking 702	mild response decreasing with curing time	accepted for exterior use around window frames, etc. accepted for interior use when material subequently sealed from occupants by barrier
polysulfide polymer rubber caulking	mild to strong response, especially when heated	used in installation of roof skin in order to maintain installer's guarantee; seal with complete air barrier
neoprene window glazing & gaskets	mild reactions, stronger when heated	accepted with possibility of sealing or replacing
drywall (unfinished)	mild to strong reactions	rejected in favour of plaster on metal lath
plaster base-coat mixes with additives	mild to strong response	rejected in favour of more basic plaster mix

Figure 16b: Testing Results on Materials for Sunnyhill (continued)

Figure 16c: Testing Results on Materials for Sunnyhill (continued)

Material	Test Results	Conclusions for Sunnyhill application only
plaster of paris and plaster of paris/lime mixes	no response when dry mild reaction when damp	accepted for indoor use
various indoor paints	mild to strong reactions esp. when relatively new and when moistened	rejected for indoor use pending further testing and experimentation with hardening techniques, e.g. baking.
6 mil polyethylene vapour barrier	mild to strong response, decreasing with airing	accepted for first interior vapour barrier, (later skinned with aluminum foil)
aluminum foil, industrial rolls, shiny side	mild response	see aluminum foil, dull side
aluminum foil, dull side	zero to mild response	accepted for interior use, dull side exposed
ARNO aluminum foil tape with removable blue backing	no response to aluminum surface; mild response to backing and glue surface	accepted for interior use with aluminum foil to provide complete seal
enamelled aluminum soffiting	mild response to coloured surface, no response to underside, (lacquered surface)	accepted as is for exterior soffiting, and as vapour barrier beneath roof insulation with lacquered side down, edges sealed with foil tape
various hardwoods unfinished	zero to mild response with hard sugar maple others mild to strong response.	maple accepted for limited interior use unfinished; subject to retesting with larger surfaces
urethane floor finishing	mild to strong reactions mild reactions even with urethane 5 years old	rejected
vinyl flooring	mild to strong reactions	rejected in favour of ceramic tile on mortar bed

Figure 16c: Testing Results on Materials for Sunnyhill (continued)

Figure 16d: Testing Results on Materials for Sunnyhill (continued)

Material	Test Results	Conclusions for Sunnyhill application only
ceramic tile	most brands no reaction to glazed surface; mild reaction to underside	accepted for indoor use
galvanized steel	no response after wiping oily film off	accepted for various interior uses, including ducting
BX armoured electrical cable	mild to strong response when new, diminishing with cleaning and age	accepted for concealed wiring
plastic drain pipes	mild to strong response	accepted for vented use in walls, with possible aluminum foil covering
copper drain	no response	accepted for exposed applications e.g. under sinks (cost prohibitive if used for entire building)
synthetic marble counters & sinks	mild response, strong when heated, esp. underside	rejected in favour of ceramic, porcelain, stainless steel
plastic laminate counters	zero to mild response to counters, strong response to particleboard	rejected in favour of stainless steel and ceramic countertops
stainless steel	no response	accepted for indoor use
porcelain	no response	accepted for indoor use

Figure 16d: Testing Results on Materials for Sunnyhill (continued & concluded)

2.1.4 Design of Features and Systems

The following subsections describe major features and mechanical systems used or intended for use in the Sunnyhill Low-Pollution Centre. Each major choice is described, major reasons for the choice are given in terms of indoor air pollution, and other advantages and disadvantages are noted.

page

a) Location 182
b) Airtight Construction Using Cavity Wall 183
c) Steel Framing and Concrete Floors 184
d) Interior Framing Separated from Vapour Barrier on Outside Wall 185
e) Deliberate Venting Through Multiple Inlets 186
f) Tempering and Filtration Of Intake Air 187
g) Recirculation of Interior Air Through Filters 188
h) Passive Solar Design 189
i) Hot Water Electric Heating Source and Potential for Heat Pump and Active Solar Heat in Future 190
j) Low Temperature Radiant Heat Distribution in Ceiling 191
k) Central Exhaust System 192
l) Lighting Fixtures Embedded in Suspended Ceiling 193
m) Generous Provision of Cupboards, Some Vented 194
n) Layout For Separation of Activities 195
o) Use of 'Bedroom Sanctuary' Concept 196
p) Central Vacuum Cleaner with Exterior Motor 197
q) Bare Floors Without Wall-to-wall Carpeting 198
r) Relatively Bare Furnishings 199
s) Unpainted Plaster Walls 199
t) House Rules 200

2.1.4 a) Sunnyhill Design: Location

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a) Location

45 kilometres northeast of Toronto, on 25 acres of rolling farmland.

Reasons:

Area is reasonably unaffected by Toronto urban smog; outdoor air can be used for ventilation a great deal of the time without additional filtration of gaseous pollutants.

Other Advantages:

Lot size provides a buffer from neighbouring pollutant sources, e.g. wood smoke. Commuting distance to Toronto is 65 km. by car, 3/4 to 1 hr. drive.

Disadvantages:

Site is close enough to Toronto that air is periodically affected by city pollution sources; site is also affected occasionally by other pollution sources such as Oshawa and Sudbury (suspected but not confirmed). Rural air contains high mould, pollen, and plant terpene levels in summer.

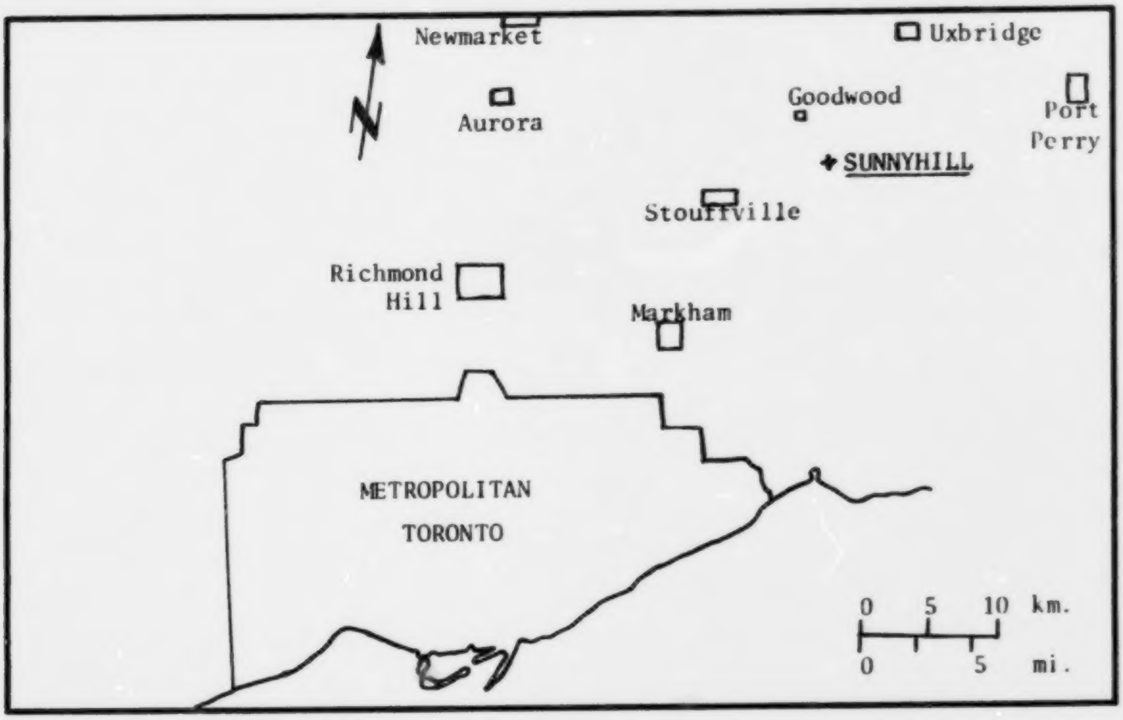
N
Newmarket
Uxbridge
Aurora
Goodwood
Port Perry
SUNNYHILL
Stouffville
Richmond Hill
Markham
METROPOLITAN TORONTO
0 5 10 km.
0 5 mi.

Figure 17: Location of Sunnyhill Low-Pollution Centre

b) **Airtight Construction Using Cavity Wall**

Cavity wall construction with 3" cavity between 6" block structural wall and brick exterior facing. Block wall is completely parged with Portland cement parging on the interior as an air barrier.

Reasons:

Parging provides complete air barrier that eliminates or minimizes flushing of wall contaminants to the interior of the building. Deliberate venting may be introduced within the building for greater control of air exchange than is afforded in leaky housing with high infiltration rates. House may be sealed off and air scrubbed inside when outdoor air quality is worse than indoor quality. Cavity allows ventilation of gas-off products of fiberglass insulation, particularly when heated by afternoon sun on brick wall.

Other Advantages:

Conserves energy by avoiding heat loss through infiltration and exfiltration;
Limits condensation in walls by limiting air and moisture flow through the building envelope to diffusion only;
Minimizes cracking and seasonal movement of structural wall because some insulation is exterior to wall.

Disadvantages:

Relatively expensive construction technique. Some difficulty insulating to desired level because of restriction on cavity width with brick facing.

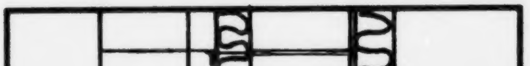

Figure 18: Cavity Wall Detail

c) Steel framing and concrete floors

Steel column, girder, and open-web steel joist construction, with poured concrete floors. Poured concrete basement walls support first floor joists at exterior of building; block structural walls support joists for upper floor. Roof support is also by steel beams and open-web steel joists.

Reasons:

To avoid softwood framing, because of sensitivity of the occupants to the smell of natural softwoods including pine, cedar and spruce.

To avoid use of plywood or particle board subflooring and roof sheathing, with its attendant formaldehyde and other emissions at levels unsuitably high for the clinical standard required in the case of Sunnyhill

To support massive concrete floors suitable for ceramic tile floors and for passive solar heat storage.

To allow long clear spans and the use of non-load-bearing partitions for interior framing, allowing utmost flexibility for future changes.

Other Advantages:

Less sound transmission between floors and less uncontrolled air leakage through floors.

Disadvantages:

Construction method considerably more expensive than conventional wood framing and flooring.

Some energy loss through continuous metal connections to roof surface.

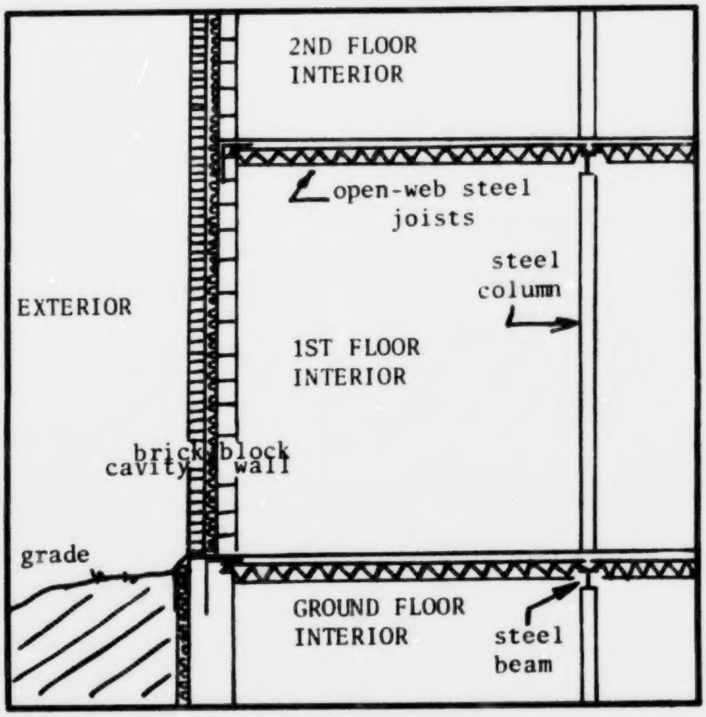
2ND FLOOR INTERIOR
open-web steel joists
steel column
EXTERIOR
1ST FLOOR INTERIOR
brick cavity
block wall
grade
GROUND FLOOR INTERIOR
steel beam

Figure 19: Steel and Concrete Structure

d) Interior wall framing separated from vapour barrier on outside wall

Plaster surfaces for exterior walls are installed on metal stud frames which are separated from the vapour barrier on the outside walls by at least 3 cm.

Reasons:

The wall cavity created provides space for installation and renovation of electrical outlets, shelf hangers, picture hangers, and other devices that puncture the wall, without damaging the vapour barrier.

Other Advantages:

Ensuring that the barrier remains intact minimizes chances of increased air pollution from the insulation and polyethylene barrier.

Although moisture damage to the wall is unlikely even with some puncturing of the vapour barrier (since the air barrier is separate), keeping the vapour barrier intact further reduces the chance of this happening.

The gap between the interior wall and the insulation allows the possibility of venting any off-gassing products of the insulation and vapour barrier into the ceiling space and from there out of the house through the central exhaust system.

Major renovation of these interior walls can take place without damaging the vapour barrier.

Disadvantage:

Added cost over methods that provide a support surface integral with the outside wall (e.g. wood studding exterior frame), both for studding and for the extra space required for the cavity.

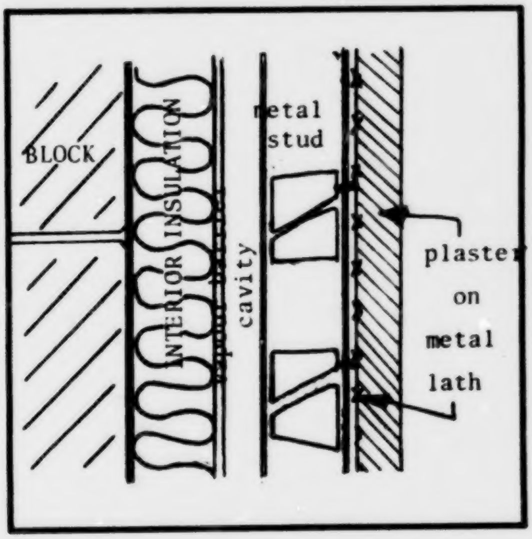

Figure 20: Interior Plaster Wall

e) Deliberate Venting Through Multiple Inlets

Use of individual brick vents in 40 locations allowing choice of or simultaneous use of many vents at different locations around the building. Most of the windows also have an awning type opening section to allow direct ventilation.

Reasons:

Outdoor ambient air varies in quality and composition (e.g. pollutant levels, pollen and mould spore counts). The Sunnyhill application requires full control of intake air rather than random infiltration. Intake air can be filtered through a choice of filtration systems.

Considerable air exchange (1 cph or greater) is required in this application to ensure flushing of pollutants to exterior and dilution of pollutants to acceptable levels.

Multiple rather than single intakes were required for three reasons:

- individual room control of air filtration is required because of variations in sensitivities among occupants
- most areas in the building require short duct intakes that are fully accessible for cleaning, in order to avoid buildup of dust and mould accumulations over long periods.
- intakes are required to be remote from the exhaust outlet (on the rooftop)

Other Advantages:

Option to use some centrally supplied air through a single cental air-to-air heat exchanger is still available. However, the favoured system for heat reclamation is use of a heat pump in the central exhaust stream. This avoids the restrictions in air-to-air systems, in which all air must come in through the exchanger in order to recapture the heat in the exhaust air. In a heat pump system fresh air can even be brought in through the windows.

Openable windows provide a psychological advantage over non-openable ones.

Disadvantages:

Continual air intake at levels greater than 1/2 air change per hour is in excess of ventilation practice for well-sealed energy-conservative dwellings. All such venting requires energy.

Multiple inlets make it difficult to take advantage of air-to-air heat exchangers between exhaust air and intake air.

Openable windows allow uncontrolled infiltration and exfiltration through cracks around seals.

Multiple vents cost more than a single central vent.

f) Tempering and Filtration of Intake Air

Two types of air supply are possible:

- 'central' ducted air supply and filtration (for some locations)
- local direct air supply and filtration (for other locations)

Central supply (if installed) involves the intake of fresh air at one location and its distribution to a number of different parts of the building through ductwork. Where possible this has been avoided in favour of local direct air supply. In some locations in the building (e.g. storage areas, some interior rooms) some ducting will be necessary. While the option is still available to couple such ducts with some exhaust air through air-to-air heat exchangers, for reasons of flexibility and avoiding contamination of intake air, heated water coils are favoured for tempering the intake air. Heat will be supplied from a hot water heating system which is fed partly by a heat pump reclaiming waste heat from the central exhaust system. The tempering coil will be followed by dust and gaseous filtration with mechanical particulate filters, and by chemisorbant and activated carbon filters.

Local supply is through small short ducts directly to the outside (see Section 2.1.4. e) "Deliberate Venting Through Multiple Inlets". The fresh air will go through a heated water coil followed by a variety of dust and gaseous filters, depending on the location of the vent and the sensitivity of the occupants in each area. Filtration units will be easily accessible for regular cleaning, changing and maintenance.

Reasons:

Occupants using this building are sufficiently sensitive to air pollutants, natural plant terpenes, natural pollens and mould spores, that in the summer season and certain other times of the year it will be necessary to filter the air to some but not all rooms in the building.

Wide variation in sensitivities of occupants dictates that filtration media may have to be different in different areas.

Other Advantages:

Tempered intake air will encourage continued venting (and thus cleaner air) and avoid cold drafts.

Heat reclamation by means of a heat pump in the exhaust stream will minimize energy loss due to ventilation while allowing the flexibility of multiple fresh air inlets.

Disadvantages:

The use of filtration media causes additional expense that would not be incurred with unfiltered intake air through vents or open windows.

Installation of two systems involves additional expense (which would not normally be incurred except in experimental situations)

g) Recirculation of Interior Air through Filters

Local air filtration devices, lodged in the ceiling spaces, can recirculate room air as well as filter intake air. The same media will be used. Separate portable air filtration units will also be available for use in clinical and other areas whenever supplementary filtration is required.

Reasons:

Reduces indoor air pollution from building sources, from occupants and from indoor activities. Interior pollutant levels from building materials, without continual filtration, may still exceed requirements particularly for severely ill patients housed for diagnosis.

Other Advantages:

Ventilation requirements can be minimized by cleaning pollutants from the interior air.

Disadvantages:

Not all chemically susceptible persons can tolerate the same filtration media, and some cannot tolerate any.

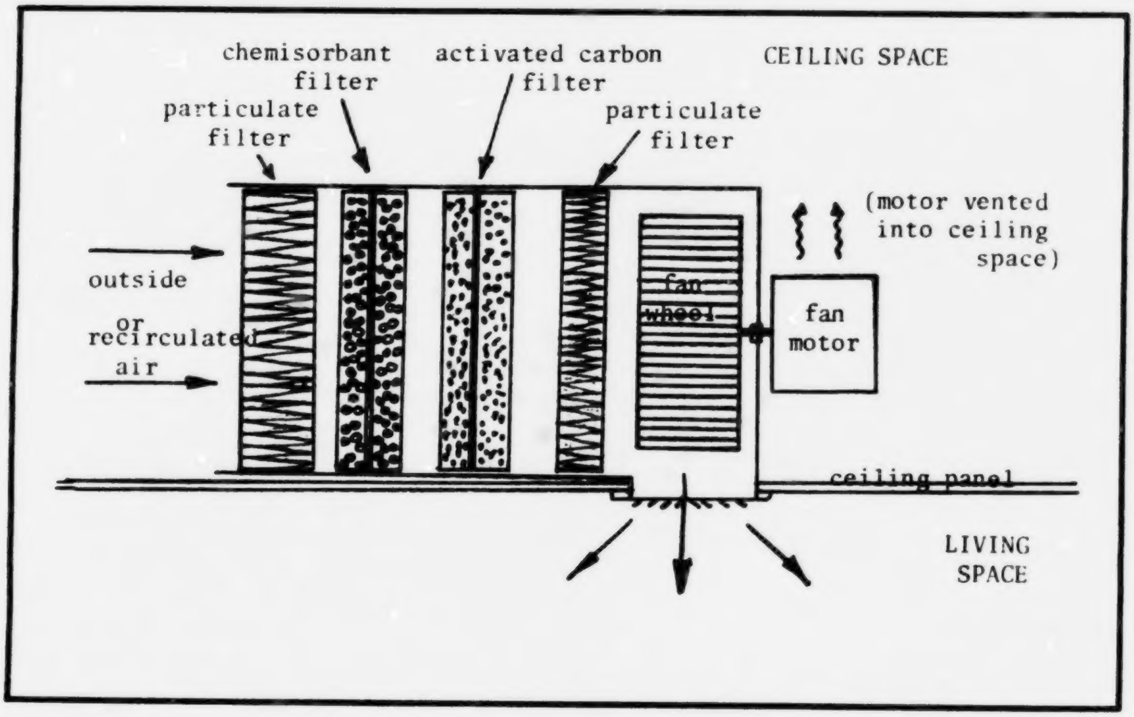
chemisorbant filter
activated carbon filter
CEILING SPACE
particulate filter
particulate filter
(motor vented into ceiling space)
outside or recirculated air
fan wheel
fan motor
ceiling panel
LIVING SPACE

Figure 21: Sequence of Filtration Media in Intake and Recirculating Filters

h) **Passive Solar Design**

Preponderance of windows on south and east faces.
Use of massive concrete and steel interior construction for heat storage.
Window spacing allows interior insulated shutters which inhibit heat loss at night.
Shading of south-facing windows to avoid summer over-heating. (Main floor shading is yet to be added on protruding steel posts shown in photo below.)

Reasons:

Passive solar heat is by far the cleanest source of heat available, since the temperatures involved are so low.
The greater the heat gained directly from the sun, the less any additional heating system will have to function, thereby minimizing pollutants from other sources.

Other Advantages:

Conservation of non-renewable energy and reduction of operating cost.
Tempering of day-night temperature swings through release of heat stored in massive building structure.

Disadvantages:

Manual use of window shutters requires training of occupants to develop energy-conserving habits.
Materials exposed to direct sunlight usually gas off more than the same material when shaded and at normal room temperature.

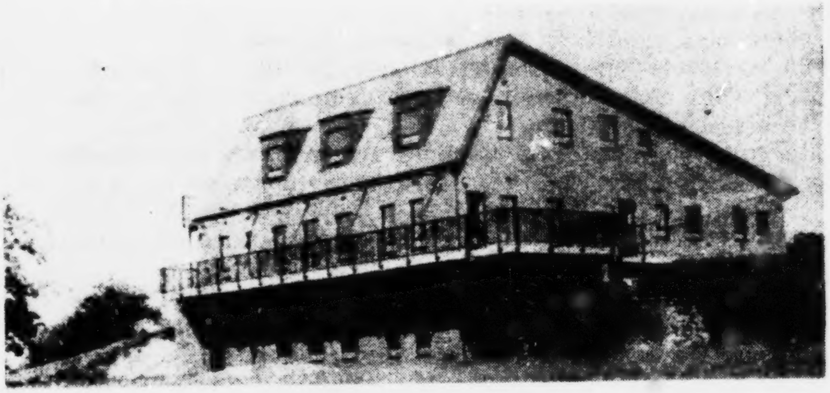

Figure 22: View of Sunnyhill from the South-east (showing windows for passive heat, shading for lower windows, provision for active solar collection on 59 degree slope south roof)

---

i) Hot Water Electric Heating Sources Including Heat Pump Connected to Solar Panels and Exhaust Air Ventilation

The initial heating source in place during the construction period has been an electric hot water boiler. The system will ultimately be fuelled from other sources as well:

1) active air solar panels on south roof face (now installed)
2) reclaimed exhaust air heat (via heat pump to be installed)
3) ground water heat (if ever needed)
4) remote fuel or wood burner (if ever needed)

The south roof face is angled at 59 degrees for optimum winter solar heat collection (see Figure 22). Air is circulated behind the dark brown enamelled steel surface, in a special chamber between the roof insulation and the roof surface. Ducts and a blower circulate cool air in the bottom of the panels and claim warm air from the top. Provision is allowed for later glazing of the exterior of the panels if economical.

Both the solar heated air and exhausted ventilation air flow over cold water coils, which are warmed by the air flow. A water-to-water heat pump delivers the heat gained into a hot water tank connected to the building's radiant heating system. The hot water boiler acts as a backup and heats the hot water tank if insufficient heat can be obtained from the heat pump.

The heat pump returns cold water to the heat exchange coils. Use of cooled water in the exchange coils allows efficient operation of the solar panels and also permits the use of the system as an air-to-water heat pump on cloudy days when the outdoor air temperature exceeds the cooling coil temperature.

Fossil fuel heating devices within the building were ruled out.

Reasons:

Fossil fuel devices have relatively high potential for creating indoor pollution at levels bothersome to chemically sensitive persons.
Heat pumps using solar heat, exhaust air heat reclamation and ground water sources will be relatively efficient.
Hot water boiler was available from temporary retrofit of an oil burner at a previous home, and provides clean safe heat.

Other Advantages:

Hot water heat is very adaptable. It can over time be fuelled by various different kinds of systems, depending on technological advances. A ground water heat pump can be easily incorporated into the system, as can remote sources such as a fuel burner external to the building. It is conceivable that wood and other sources would be feasible in the longer term if good pollution control devices are employed and if they could be used 'off-peak', i.e. in the right weather conditions to heat storage water.

Disadvantages: Initial cost of heat pump, storage tanks, and solar ducting system.

j) Low Temperature Radiant Heat Distribution in Ceiling

Plaster drop-in ceiling panels manufactured on site, with small diameter flexible copper pipe embedded in them, for circulation of hot water for radiant heat.

Access for system installation and interconnection is through adjacent non-heating panels.

Reasons:

Heat panels allow lowest temperature application of heat through direct radiation from ceiling panel to the occupant. Potential for air pollution is extremely low.

Lack of registers or radiators within room allows full flexibility for different uses of rooms.

Lack of radiators allows easier cleaning of room, less accumulation of dust.

Local heat allows separation of air from different room areas, in contrast to dwellings with central air circulation.

Other Advantages:

There is some evidence that air temperatures required in radiant heated houses to maintain occupant comfort are a few degrees C less than those required in convection heated homes, leading to overall energy savings.

Hot water heat is adaptable to different heat sources, including electric water boiler, solar panels, heat pump, and remote wood or other fuel burners.

Ceiling panels give shorter response time when occupants desire heat than would coils embedded in the more massive floors. The building can be zoned and unused areas kept cooler.

Use of panels rather than continuously plastered ceiling allows for future changes in and experiments with lighting, heating, wiring and venting.

Disadvantages:

The system is costly and labour-intensive, at least at this stage. There are no reasonably priced commercial systems yet available; panels must therefore be manufactured on site.

Any system leaks could cause local water damage.

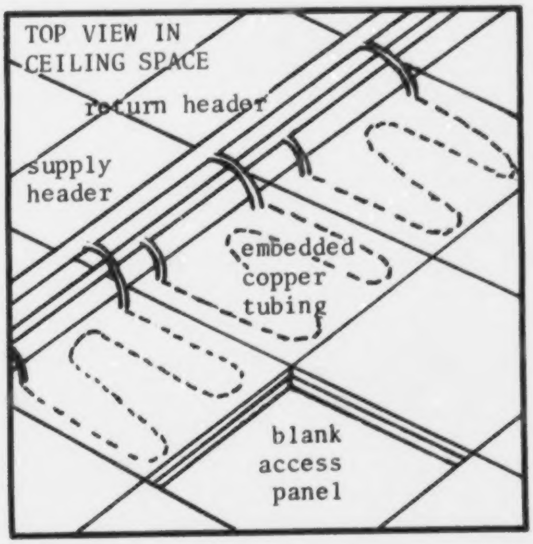

Figure 23: Radiant Heating Panel

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k) **Central Air Exhaust System**

Use of central exterior exhaust fans mounted on the roof (motor outside).
(Two Nutone 1000 cfm 'mushroom' exhaust units, with 10 " duct)
Reclamation of heat with a heat pump in the central exhaust stream.

Reasons:

Allows deliberate flushing of pollutants from various parts of the building, including rooms, cupboards, appliance enclosures, and various interior building spaces such as within walls and ceilings.
Waste heat is ideal source for efficient heat pump operation.

Other Advantages:

Use of a central exhaust system allows the flexibility to tap into the system later to provide venting for additional individual pollutant sources.

Disadvantages:

Difficult to properly balance exhaust system with many inlets. Automatic dampers with computerized balancing control and in-duct pollution monitors may be needed in the long term to make best use of this system; when used manually such a system is dependent on occupant choice and habit, and occupants may forget to increase venting when they need it the most.

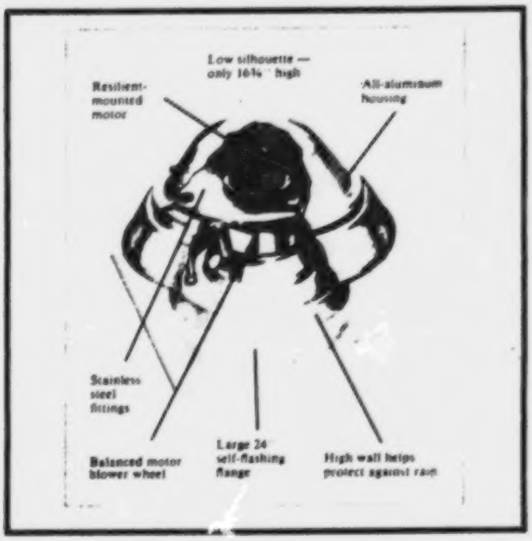

Low silhouette — only 16¾'' high
Resilient-mounted motor
All-aluminum housing
Stainless steel fittings
Balanced motor blower wheel
Large 24'' self-flashing flange
High wall helps protect against rain

Figure 24: Exterior Exhaust Fan

1) Lighting Fixtures Embedded in Suspended Ceiling

Both incandescent and fluorescent fixtures will be installed in ceiling panels, with venting of gas-off products of hot bulbs and fixture housing into vented ceiling spaces.

Full-spectrum fluorescent tubes will be used; installation will allow experimentation with electromagnetic shielding to determine possible effects if any of fluorescent fixtures and different light spectra on occupants.

Reasons:

Hot fixtures and lighting tubes can lead to gassing off of materials and burning of air-borne dust; installation in ceiling space allows venting.

Number of dust-accumulating articles in a room is reduced compared to conventional housing with portable lamps.

Other Advantages:

Drop ceiling allows repositioning and rewiring of lighting system to adapt to changes in use of different parts of the building.

Decrease in cooling requirements in summer.

Disadvantages:

Free heat from fixtures is only used after reclamation in exhaust air by heat pump.

Ceiling lighting provides less flexible task lighting than small portable lamps; some portable fixtures may prove necessary in any case.

Room lighting requirements limit flexibility in the ceiling heating system design.

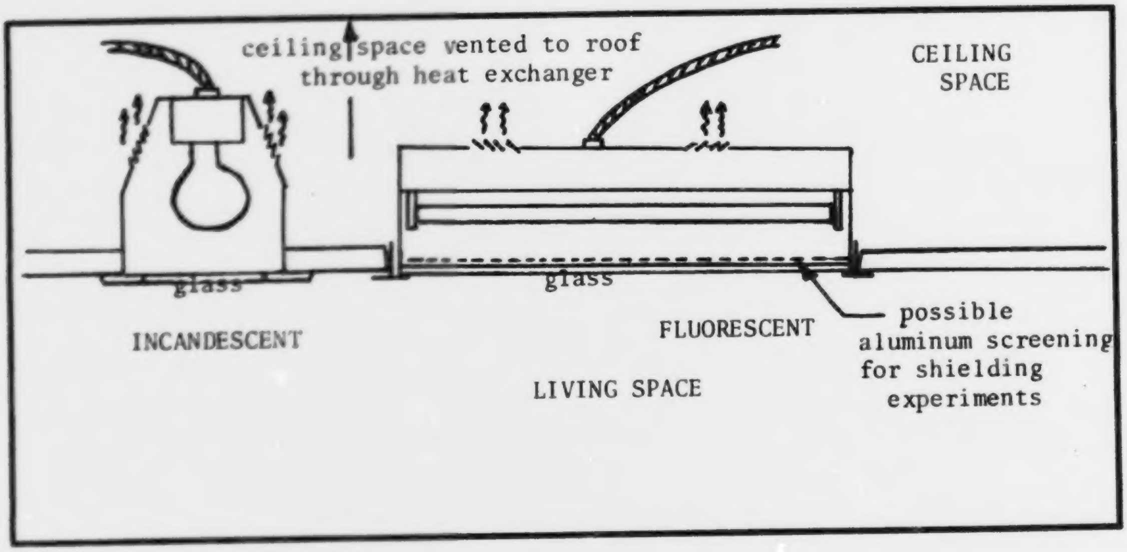

ceiling space vented to roof
through heat exchanger
CEILING
SPACE
glass
glass
INCANDESCENT
FLUORESCENT
possible
aluminum screening
for shielding
experiments
LIVING SPACE

Figure 25: Light Fixtures Embedded in Ceiling Space

2.1.4 m) Sunnyhill Design: Vented Cupboards

---

m) Generous Provision of Cupboards, Some Vented

Ample provision of large closable cupboards in virtually every room area. Cupboards can be vented by hooking into the general exhaust system. Vented cupboards will have cloth-filtered air vent.

Reasons:

Separation of the occupants from polluting objects that are not used continually. Objects brought into houses and accumulated there represent in total a major source of indoor air pollution in residences.

Reduction of clutter makes frequent cleaning of rooms easier.

Flushing of air contaminants from materials stored in cupboards reduces potential indoor air pollution later when products used.

Other Advantages:

Flexibility is added to room areas because furnishings, decorations and use can be changed more easily than when many objects are placed throughout the room.

Disadvantages:

Cloth filter must be cleaned or changed regularly. Without the filter dust is deposited in cupboards rapidly.

Cupboard hardware is in general more costly than providing bare walls.

It is difficult to find materials for shelves and doors that themselves do not add more indoor pollution than bare walls.

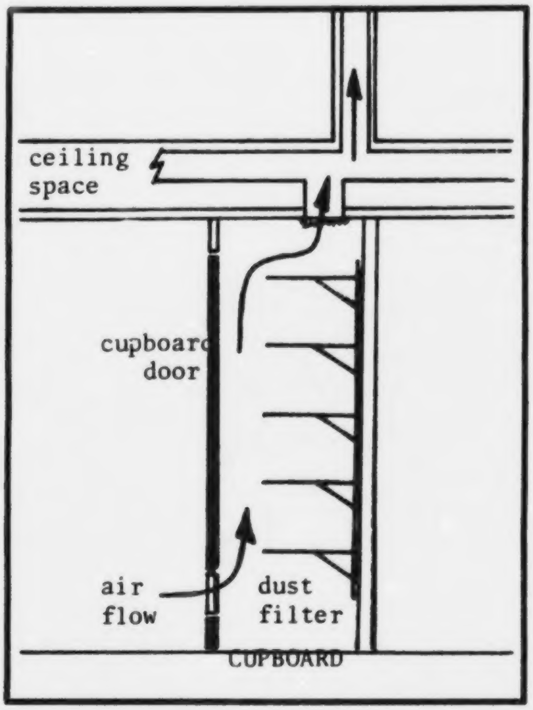


Figure 26: Vented Cupboard

n) Layout for Separation of Activities

All rooms are closable, to separate occupants from activities in adjacent rooms.

Reasons:

Occupation of the building by persons of varying chemical sensitivities means that some occupants will undertake activities that may create indoor air contamination that others cannot tolerate. (e.g. reading a newspaper)
Odours from food preparation and serving may aggravate symptoms in food sensitive persons.
See also Section 2.1.4 o) "Bedroom Sanctuary" following.

Other Advantages:

Noise separation.
Allows separate air control and reduced heating in unoccupied areas.

Disadvantages:

Modern trend is to open concept; in the Sunnyhill example glass walls on kitchen and open balcony over seminar area provide an illusion of open-ness even though rooms are still separable.

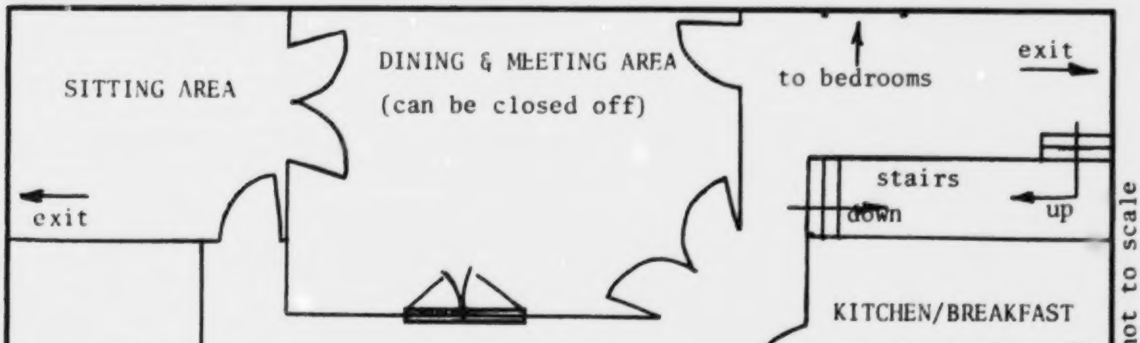

SITTING AREA
DINING & MEETING AREA
(can be closed off)
to bedrooms
exit
stairs
down
up
exit
KITCHEN/BREAKFAST
(can be sealed off from other areas and is well ventilated)
this drawing not to scale
stairs
up
railing
(this area open to ground floor seminar room; can be closed off by doors shown on main floor)
entrance
lift
window wall
vented cupboards
railing
south-facing windows
exit

Figure 27: Main Floor Detail Showing Separation of Areas

o) **Use of 'Bedroom Sanctuary' Concept**

Bedroom/dressing room combinations with a minimum of furniture and little or no storage of clothes in the bedroom itself.

Reasons:

Having a bare, easy-to-clean bedroom makes it more likely that this one 'super-clean' room will afford the occupant a 6-8 hour stretch in the least possible indoor air pollution.

Clothes easily accumulate pollutants from other places, e.g. trace odours of tobacco and perfume, dust, mould etc. These are best stored in vented cupboards to which the occupant is not exposed at night.

Other Advantages:

Disadvantages:

Bedrooms tend to be a little smaller than normal, though combination bedroom/dressing room may be larger.

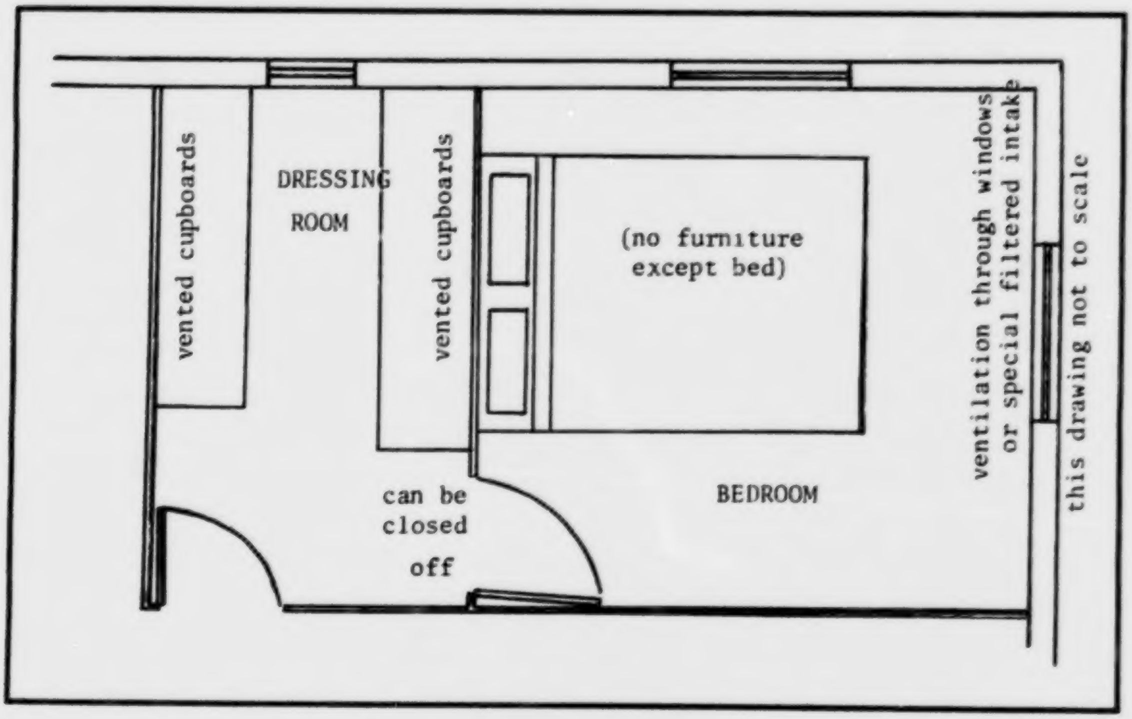

vented cupboards
DRESSING ROOM
vented cupboards
(no furniture except bed)
can be closed off
BEDROOM
ventilation through windows or special filtered intake
this drawing not to scale

Figure 28: Bedroom 'Sanctuary' Concept

---

p) **Central Vacuum Cleaner with Exterior Motor**

Powerful central vacuum cleaner is installed in metal cupboard on outside of north wall. Piping provides vacuum outlets throughout the building.

Reasons:

Motor and dust exhaust from conventional portable vacuum cleaners can cause severe reactions in highly allergic persons, and increase indoor air pollution (e.g. ozone concentration, from motor sparking).

Some central vacuum installations have the motor mounted in the basement and dust piped outside; in totally exterior mounting even motor odours are excluded from indoor air.

Building is more likely to be cleaned regularly if vacuuming is convenient and does not cause reactions in persons doing the work.

Other Advantages:

Increased convenience for cleaning.

Disadvantages:

Piping available at reasonable cost is plastic, and joints must be sealed with solvent cement. (Indoor air problems from these sources can be mitigated by wrapping pipes and joints with aluminum foil and sealing joints with foil tape; this is tedious but effective).

In a building of this size, several hose sets are required. The plastic hoses take a year or more to gas to the point where their presence in a room will not cause significant problems for highly chemically susceptible persons. (If necessary hose can be wrapped with flexible aluminized polyethylene.)

q) Bare Floors without Wall-to-Wall Carpeting

Bare hardwood or ceramic tile floors, with small scatter rugs only, when needed at all.

Hardwood system, where installed, consists of Robbins steel channel flooring system, mounted directly on concrete.

Reasons:

Large area synthetic rugs are a major source of formaldehyde and other indoor pollutants. Carpets exposed to sunlight gas off even more.

Reduction of dust, to accommodate highly dust-sensitive occupants.

Steel channel system does not require plywood or softwood subflooring.

Besides the problem of finding carpet material that does not gas off significantly, the practicality of regular cleaning must be taken into account. Ability to wash all fabrics in the building periodically is necessary in the Sunnyhill application, since fabrics accumulate contaminants over time. Testing will continue to determine whether some rug fabrics can be tolerated and properly maintained by steam cleaning without other volatile cleaners.

Other Advantages:

Bare ceramic floors in southern exposures will act as good heat absorbers for passive solar storage.

Disadvantages:

Present trend is to more use of wall-to-wall carpeting; plushness is a generally accepted status symbol.

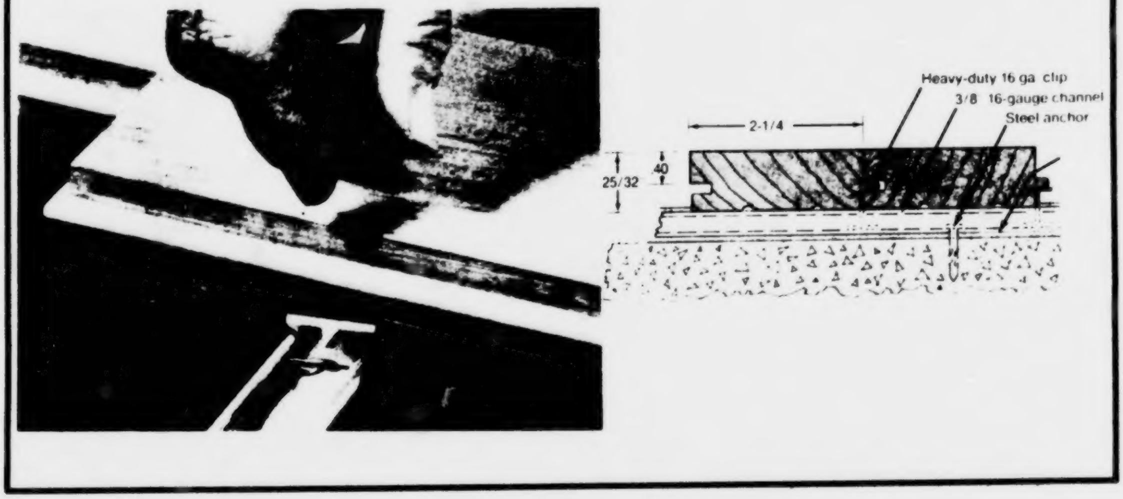


Figure 29: Steel Channel Supports in Hardwood Flooring System

r) **Relatively Bare Furnishings**

Interior furnishings are being selected with care to avoid materials such as particle-board and treated fabrics that may release formaldehyde and other gases. In general, relatively bare hardwood, metal and glass furnishings with removable natural fabric padding or coverings are acceptable, while plush synthetic furnishings with non-removable padding and coverings are not. Plastic furnishings are not acceptable in the Sunnyhill application.

Reasons:

To minimize air contamination by low-levels of pollutants, and to minimize skin contact between occupants and sensitizing chemicals.

Other Advantages:

Such furnishings can be relatively light and moveable, providing more flexibility in changing use of rooms on short order.

Disadvantages:

Trends are to highly synthetic and plush furnishings, often with a great deal of plastic. Care will be required to establish a decor that allows an acceptable level of comfort and that is as 'inviting' to occupants and guests as other modern furniture.

s) **Unpainted plaster walls**

Textured plaster walls, applied on metal lath, left unpainted until or unless further testing leads to selection of a low-outgassing paint that will be acceptable in this clinical environment.

Reasons:

Avoidance of gas-off products of wall-board and paint.

Disadvantages:

Unsealed plaster may absorb and re-emit moisture and air pollutants from indoor air. Cleaning of walls is not as easy as with paint, although vacuuming of dust is still possible and retouching with a plaster whitewash is as feasible as repainting a conventional wall.

t) House Rules

Certain house rules are posted at the entrance and in other strategic locations to remind visitors and temporary occupants of certain restrictions that are necessary to maintain an atmosphere of minimum indoor air pollution:

- strictly no smoking within the building
- no aerosol products, perfumes or other scented products to be used or worn inside the building

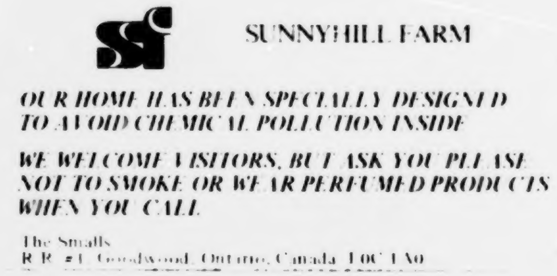
Reasons:

Tobacco smoking can cause major indoor air contamination, and presents problems almost universally for chemically susceptible persons.

Chemically sensitive persons are often sensitive to various perfumes and product scents, as well as propellant gases.

Disadvantages:

Some people are offended by the idea that their smoking or their choice of toiletries may make others ill.



SUNNYHILL FARM

OUR HOME HAS BEEN SPECIALLY DESIGNED TO AVOID CHEMICAL POLLUTION INSIDE

WE WELCOME VISITORS, BUT ASK YOU PLEASE NOT TO SMOKE OR WEAR PERFUMED PRODUCTS WHEN YOU CALL

The Smalls
R.R. #1, Goodwood, Ontario, Canada L0C 1A0

Figure 30: Sign at Entrance to the Sunnyhill Low-Pollution Research Centre

2.1.5 Construction Techniques and Supervision

Most of the individual construction techniques used in the Sunnyhill example are already commonly used either in residential or commercial construction in Canada.

Among the less common methods used are:

- cavity wall construction, and
- the method of attaching and sealing the interior vapour barrier

The choice of materials and the unusual mix of commercial and residential methods makes the building unique and the construction supervision far more demanding than conventional construction. Almost constant construction supervision is required to ensure:

- precise conformance to plans
- that no materials are substituted for those specified
- that unexpected problems arising during construction are solved in a manner that does not violate the low-pollution criterion

While these goals are similar to those of supervision for conventional construction, it must be stressed that virtually no subcontractors employed on the site understood the purpose of the building and its design sufficiently well to know the significance of even minor alterations of design as a result of field problems.

a) Cavity wall construction

A cross-section of the cavity wall is given in Figure 18. Figure 19 shows also how the floors are supported by the structural block layer.

The primary problem encountered was that of finding a sub-contractor who was familiar with cavity-wall construction. Local contractors denied any knowledge of this method. The chosen subcontractor was found inadvertently by the author as he drove by and recognized a cavity-wall school building going up in a northeast Toronto suburb.

The efficiency of a cavity wall in performing its various functions - shedding of rain, insulation of the building, structural support, and air barrier, depends on careful bricklaying technique and installation of the exterior insulation at the same time as the brick wythe is built up. Metal block ties were used every two feet to tie the brick and block layers together. Insulation slabs were pushed between the block ties before bricks were laid in front. The effectiveness of the insulation depends on conscientious installation of these slabs, without gaps.

The cavity effectively ventilates the back surface of the brick and keeps the insulation dry. Dripping mortar must be removed from the cavity as each brick layer is laid, so that the cavity is continuous and moisture is not led across it from the brick to the insulation. In practice, constant supervision of this aspect is virtually impossible and the subcontractor's crew was on occasion inclined to omit scraping the back of the brick, to save time.

Part of the advantage of the cavity wall construction is the capability of placing insulation exterior to the structural block wall, and continuous past the edges of poured concrete floors, as shown in Figure 19. However, present energy conservation standards require more insulation than previously, and the use of only a 2" slab of R8 insulation exterior to the block was not considered sufficient.

Building Code regulations prevented the use of a wider cavity without using ties made of masonry between the brick and block wythes. As this would have introduced direct heat loss pathways, the idea was rejected in favour of adding an additional R8 insulation layer inside the building against the structural block wall. With all the other wall components, including the cavity, this brought the thermal insulation rating of the wall to about R-20.

In terms of the goal of minimizing indoor air pollution, the decision to add insulation on the interior of the block wall was a compromise, and caused a number of problems in meeting both energy conservation and clean air goals. These are described in section 2.1.5 b) following.

Anodized aluminum windows were installed across the cavity and insulation was made continuous to the inside of the window frame and to its thermal break (see Figure 31). The thermal break, made of a flexible vinyl rubber compound, emitted a strong odour when the frame was heated in the sun. Prior to installation, a 1 cm. width of aluminum foil tape was applied to the thermal break where it was exposed on both sides of the frame. This was effective in sealing in the odour.

In practice it was difficult to ensure that insulation was properly packed behind the window frame, since there was little clearance between the frame and the block. Since the cavity is open to outside air circulation at freezing temperatures in the winter this is one flaw in the design - the slightest separation of insulation behind the window frame will allow some air circulation across the thermal break and therefore a heat leak from the warm side of the metal frame.

This and another heat loss problem might have been solved by making larger openings in the block and allowing for insulation continuously around the edge of the block to the window. The present design allows a heat leakage path adjacent to the windows through the block and only one layer of insulation rather than through two layers as on the face of the walls. The seriousness of this design error is partially mitigated by the use of interior

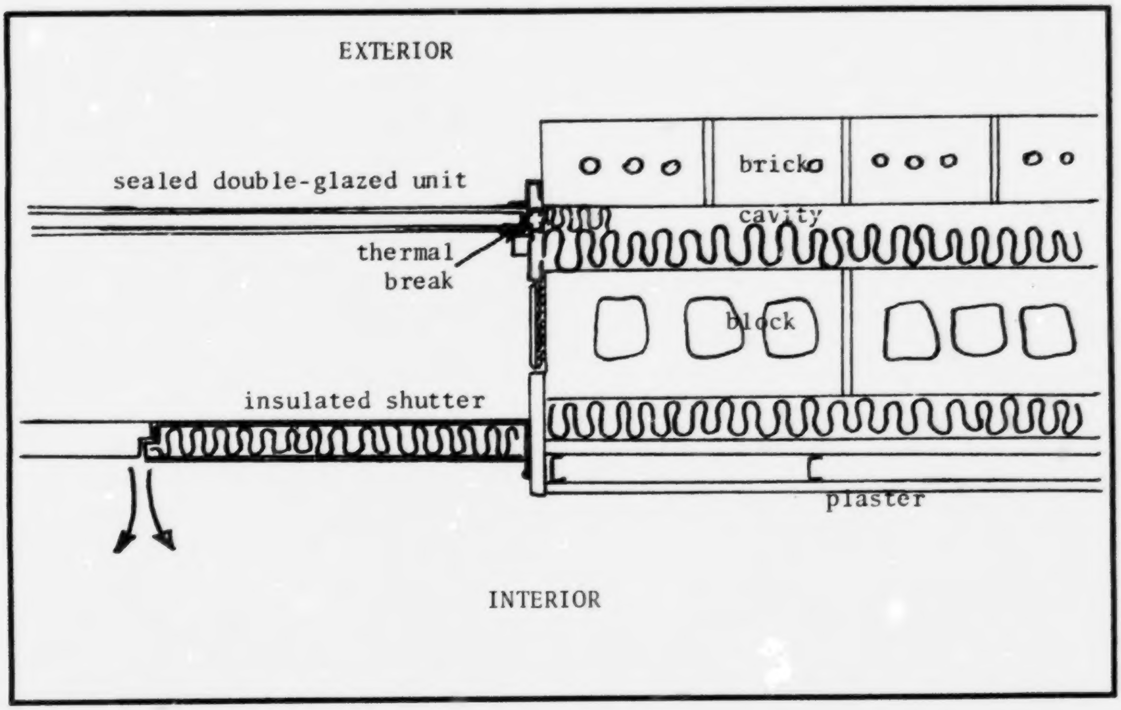

EXTERIOR
brick
sealed double-glazed unit
cavity
thermal break
block
insulated shutter
plaster
INTERIOR

Figure 31: Window Frame and Cavity Wall Detail

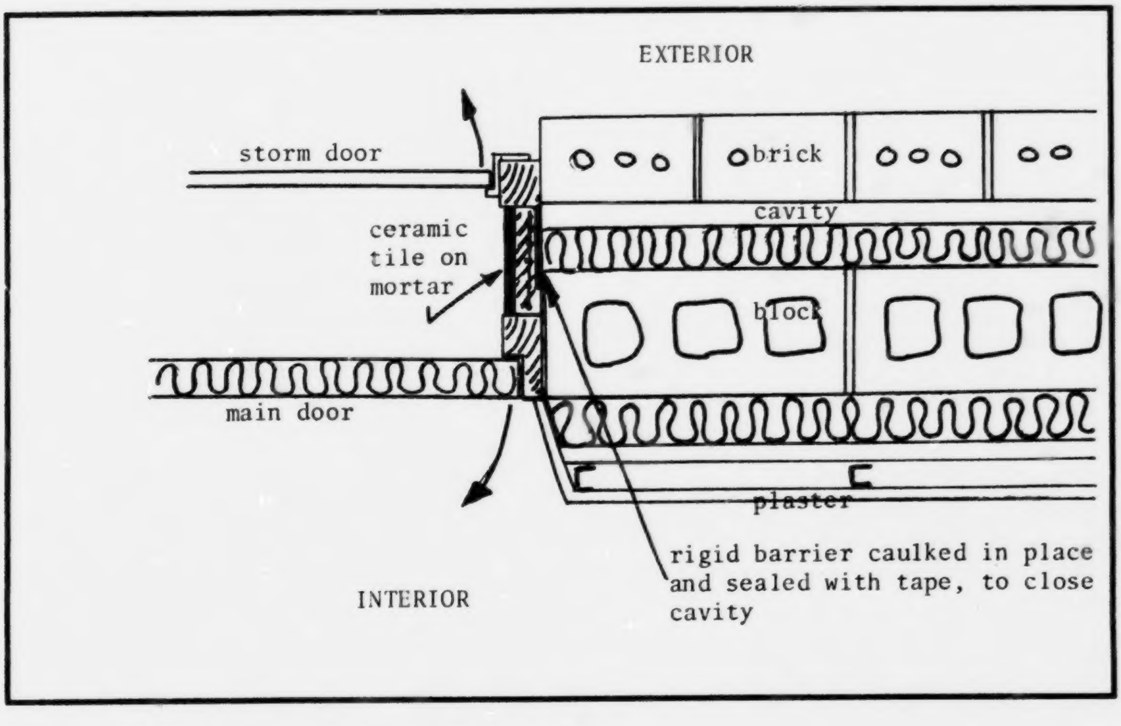

EXTERIOR
storm door
brick
cavity
ceramic tile on mortar
block
main door
plaster
rigid barrier caulked in place and sealed with tape, to close cavity
INTERIOR

Figure 32: Doorway and Cavity Wall Detail

insulating shutters continuous with the interior insulation layer and of equivalent R-value (R8). While windows are receiving solar radiation there is little if any problem, and when they are in shadow or at night the shutters may be closed to minimize loss.

The closing of the cavity at the doorways involved similar energy loss problems, and in addition posed a potentially serious indoor air pollution problem. Throughout an extended period during construction, the cavities were left unsealed at the doors, although extra insulation was stuffed in them to eliminate drafts directly into the building. Storm doors had been installed on the brick layer, but full insulated exterior doors on the block layer had not been installed. Late in the afternoons in the warmer months, an objectionable odour arose inside the main floor particularly adjacent to the west side of the building. Figure 32 illustrates the doorway detail.

The odour was determined to be coming at least in part from the heated insulation within the wall cavity, which was then in effect open to the interior of the building. Late in the day the brick face on the west side of the building became quite hot to the touch in the direct sunlight, and the cavity appeared to act as an oven to bake out the unreacted binding chemicals in the fiberglass insulation.

In order to seal the cavity fully, a rigid barrier sealed with silicone caulking was installed, with the caulked edges in turn sealed with aluminum foil tape in order not to leave caulked surfaces accessible to the indoor air. It is easy to see how the importance of such details might be overlooked by unsupervised subcontractors, and the consequence could have been continual leakage of cavity gases into the interior of the building.

b) Attachment of Interior Insulation

On the warm side of the structural block wall, an additional layer of R8 rigid fiberglass batt insulation was installed. Just prior to installation the cement parging air barrier was inspected for cracks and silicone caulking was applied to any potential air leaks, particularly where the wall had been deliberately punctured for wires to exterior lights, pipes for exterior taps, or for vent installation. Three conventional options for attachment of the insulation were rejected:

- o strapping (to avoid softwood odours and to avoid punching holes in the cement parging air barrier)
- o adhesive (to avoid the introduction of more odours)
- o mechanical fasteners (to avoid puncturing the air barrier)

The method adopted consisted of stringing steel wires in a W-shaped fashion from floor to ceiling, fastened at each end with a Tapcon conrete screw. The insulation slabs were slipped behind the taut wires and packed carefully, sealing all gaps.

2.1.5 b) Sunnyhill Construction: Interior Insulation (continued)

A 6 mil polyethylene vapour barrier was then slipped behind the wires, tucked around the top of topmost insulation slab, and tucked completely underneath the bottom-most slab (the weight of the insulation itself helping to assure a reasonable seal at the bottom). Figure 33 shows the detail of this method.

The polyethylene barrier was mounted in 12' wide sheets, continuous from floor to ceiling. Vertical joins were lapped 6-8 inches and taped with Union Carbide polyethylene tape. To assure permanent bond particularly when installed in cold weather, a portable hair dryer was used to heat the tape after application, while pressing it to join any unsealed areas.

Inspection of the polyethylene tape after several months and even up to two years showed it to be effective as long as it was not exposed to direct sunlight. Tape exposed to sunlight, particularly around the windows became brittle and often lost its seal. Tape in the middle of the wall and in shade stayed flexible. Inspection of tape in areas that were subsequently covered with an aluminum foil skin revealed that tape covered in this manner remained more pliable than tape left exposed.

After all joints were taped, additional wires were joined horizontally across the 'V' of the near vertical wires, and tightened until the entire insulation and vapour barrier assembly was held snugly to the wall.

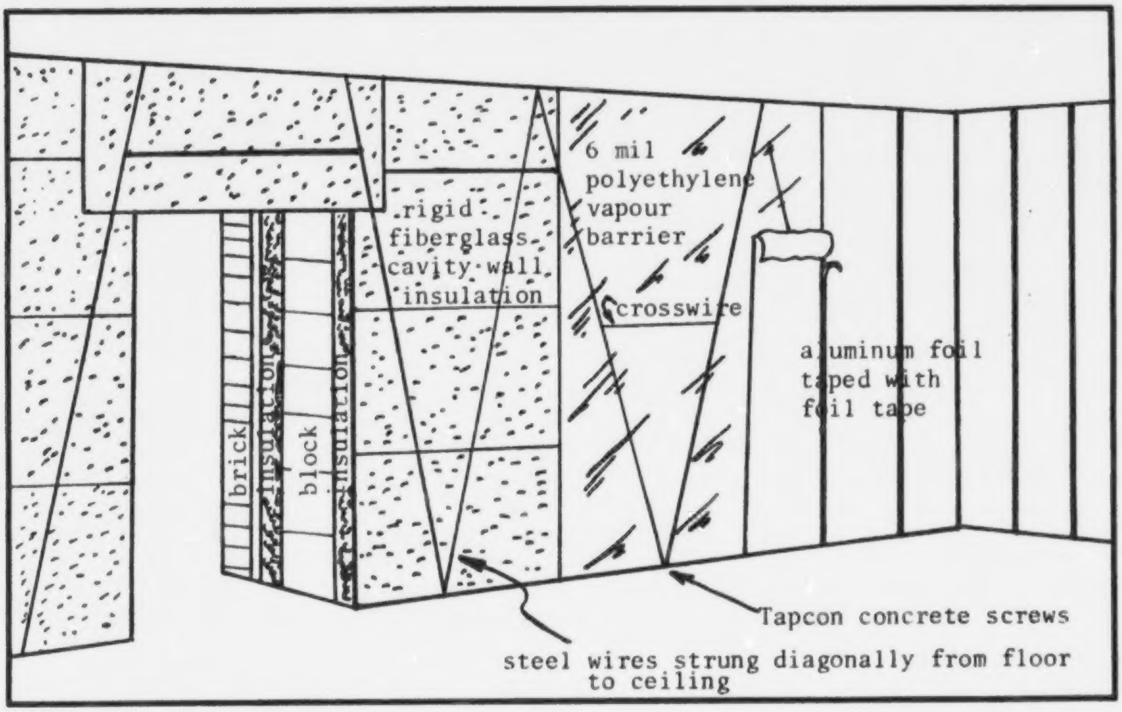

6 mil polyethylene vapour barrier
rigid fiberglass cavity wall insulation
crosswire
aluminum foil taped with foil tape
brick
insulation
block
insulation
Tapcon concrete screws
steel wires strung diagonally from floor to ceiling

Figure 33: Attachment of Interior Insulation

During the period in which the rigid fiberglass slabs were in place without the vapour barrier, the odour of the insulation was sufficient to cause at least mild physical symptoms in the occupants and in several cases severe symptoms to chemically susceptible visitors.

The polyethylene vapour barrier seemed to seal this odour adequately but the smell of the polyethylene was in turn identifiable and appeared to cause at least mild physical symptoms in the occupants. The odour of the polyethylene tape when exposed to sunlight was particularly objectionable. Since considerable area would remain exposed for some time during construction, and since the author's family had at this point taken up temporary lodging in a basement storage area, it was decided to add a further barrier to the polyethylene.

Heavy duty aluminum foil in industrial rolls 457 mm. (18 in.) wide was purchased for experimenting with a skin over the polyethylene. ARNO aluminum foil tape, stripped into 12 to 20 mm. (1/2 to 3/4 in.) widths, was used to seal between strips of foil. The foil was hung like wallpaper, fastened with tape on the top and sides, and tucked underneath the insulation and polyethylene vapour barrier at the bottom.

The procedure proved tedious but effective in reducing the odour of the polyethylene vapour barrier. During application the effect of the polyethylene barrier became more identifiable as less was exposed, since adverse reactions in different parts of the building could be more easily compared. When the remaining polyethylene was in direct sunlight the odour was particularly pronounced.

Several substitute brands of foil tape were used due to difficulties in supply. The ARNO brand proved to be less likely than others to come loose. One of the alternative brands had a mild but objectionable odour that did not dissipate over a period of more than a year and a half.

Narrow widths of tape (12 mm.) proved more likely to come loose than 20 or 25 mm. widths. Most areas have shown no tendency for the tape to loosen during a period of two years. Those strips that loosened did so within days, possibly a function of dust or moisture during application, or of a variation in manufacture. The tape adhered well to both the polyethylene and the aluminum foil barriers, as well as to the underside of the metal forming pans on the ceiling, even when rust was present. In some places the tape also adhered well to the concrete floor but in others it lifted. In general its use on concrete was not found to be reliable.

In several areas where foil tape lifted after a relatively short period moisture problems were discovered. For example, a leak from a break in exterior caulking on a raised deck area had allowed water to enter the wall cavity.

While the use of caulking to seal the vapour barrier would have been more effective than tape, the introduction of caulking in large quantities to the interior was considered unacceptable in terms of added indoor air contamination. Some combination of caulking and taping may turn out to be optimum.

The inevitable loosening of some vapour barrier seals over time is not considered to be a severe problem. Considerable attention was paid to ensuring that the cement parging air barrier was complete (by caulking cracks and punctures) . Some slow migration of moisture through the occasional gap in the vapour barrier is not likely to cause structural damage from condensation. Usually moisture problems arise when there is considerable air flow through gaps in the structural wall, rather than slow diffusion of moisture through the wall itself. The most likely location for condensation within the wall is on the inside surface of the brick cladding, and this is well ventilated by a 1 inch cavity.

A gradual increase in the number of spots where aluminum tape may loosen over a period of many years is also not expected to pose a significant air quality problem. Interior plaster walls will be separated from the vapour barrier by a narrow cavity (3 cm.), and this volume will be subject to some venting through the central exhaust system. Any gassing-off of the insulation and the plastic vapour barrier materials is not expectd to pose a problem since the bulk of the material remains well sealed. In most areas this cavity will be accessible for inspection (but not adjustment), and the effectiveness of the seal and the concentration of the resulting gas-off products can be tested over time.

c) Construction Supervision

It is the function of the construction supervisor on any project to enforce conformity to plans and specifications. In actual practice, most plans contain a certain tolerance, and field alterations are common. In Canadian residential construction, materials may be substituted due to varying availability, openings in walls may sometimes be shifted slightly in order to suit the convenience of the bricklaying trades, and various other modifications may be made as each trade encounters minor installation problems that are not anticipated on the construction drawings or in the specification sheets.

In low-pollution construction, it can be expected that subcontractors may not readily understand either the reasons for or the importance of many building features noted on the drawings and specifications. It is therefore difficult for them to make minor alterations without risking some violation of the purposes of the original design. This is probably just as true at the present time in regard to energy conservation features, although trades are starting to gain a better understanding of the need for a well-sealed air and vapour barrier, installation of insulation without gaps, etc.

Three examples following will illustrate how seemingly minor changes or problems may affect the degree to which indoor air may become polluted.

1) Use of petroleum products and gasoline-powered machines during construction

In a conventional installation, a concrete flooring subcontractor would not think twice about spillage of gasoline and oil within or around a building under construction, except insofar as fire safety is concerned. During the pour of Sunnyhill's main level concrete floor, concrete finishing machines were placed on the hardening surface and the workers proceeded to trowel the surface smooth with the gasoline-powered machines.

Several of the machines had been over-greased and tended to fling lumps of grease across the surface. One ran out of gas and the labourer filled it on the spot without care to ensure there would be no spillage. Both of these incidents, though seemingly trivial, left areas on the concrete floor that had a strong odour that could severely affect a chemically susceptible person if it persisted within the final enclosed building. In this case the spots were scrubbed with water and low-odour industrial detergent, flushed generously with water and subsequently baked by being in open sunlight for some time after the concrete was cured.

In construction of a similar dwelling in New York state, it was reported to the author that a spill of diesel fuel within a wall cavity was not as easy to clean up, and without treatment would have presented a severe and persistent hazard to the chemically susceptible occupant.

2) Substitution of industry standard products for specified materials

In low-pollution construction, various materials may be specified that are not well-known and commonly used. Subcontractors are faced with decisions on substitution if supplies of specialized materials run out. Close supervision and attendance of the general contractor on site is required to ensure that substitutions are not made that will jeopardize the interior environment.

In the Sunnyhill example, the roofing contractor used a polysulphide polymer rubber caulking compound that had been mutually agreed to be acceptable enough to the designer for his purposes and at the same time adequate in the subcontractor's view to guarantee against leakage of the roof. The team installing the roof panels followed instructions closely until one man ran short of the required caulking tubes. In his tool kit he had a tube of Mono caulking that was left from a previous job. Without hesitation he put this to use, only to be required later to remove and scrape down areas to which it had been applied, because of an overpowering odour that was unacceptable to this author (the incident took place in the vicinity of planned clinical rooms). The worker was familiar with Mono brand, enjoyed using it, and could detect no odour at all to it.

The mistake was not deliberate, yet it could have had considerable consequences insofar as air quality and meeting the building specifications are concerned.

3) Imperfections in concrete work

When the ground floor and main floor concrete floors were poured, several difficulties arose which may have affected indoor air quality and which also created further problems for later stages of interior finishing.

As a result of mechanical difficulty with a concrete pump, delays were incurred during pouring of the slabs. Several concrete ready-mix trucks were kept standing longer than desirable. At the same time (and unannounced to the author until later) one truck had broken down on the 6-mile route from the plant to the site and was delayed even longer.

The resulting pour was more difficult than usual to level, and experienced more shrinkage and cracking than the later top floor pour. The subcontractor later offered to fill in shallow spots with an epoxy-concrete filler, which was unacceptable because of the introduction of other materials that could gas off into the interior of the building. While the problem is not severe, it has led to two consequences:

- Increased air flow from the soil beneath the slab into the building. Although measurements have not been made to confirm this, it is understood that radon and other soil gases can migrate into the indoor environment through cracks in basement floors and around slab edges.
- Alteration of interior plans, to include more ceramic tile areas and less hardwood flooring, because of the difficulty of leveling the steel channels used in the flooring system. Since the ceramic tile is laid on a thick reinforced mortar bed (25-40 mm.), irregular contours and cracking of the slab are no longer significant problems.

The simplest solution to decrease the concentration of soil gases in the basement is to caulk the open cracks and areas around the slab edges that pull away from the vertical poured concrete wall. While this is intended in the long term, occupation of the basement area by the author and his family during the remainder of the interior construction has precluded the use of caulking or even cementitious sealing compounds. Increased venting of the basement area, with balanced makeup air, has been adopted as an interim solution. (Venting with balanced makeup air is more desirable than venting by negative pressure alone, since reduced pressure may increase outgassing of the soil significantly.)

A fourth example had a bearing on energy conservation:

4) Moving of Window Openings

Despite a carefully developed plan which took into account column widths and window sizes needed to achieve an integral or half-integral number of bricks, the bricklaying subcontractor tended to want to exercise independent judgment on the position of window openings in the cavity wall.

In normal construction, variation of position by several inches would not have in any way adversely affected the remaining plan, and the subcontractor was used to this. However, since Sunnyhill was designed as a passive solar building, positions of window openings affected positions of interior insulating shutters. The window spacing across each wall was designed to accomplish full opening and foldback of half-width shutters on the interior wall, and any variation defeated the proper movement of these shutters.

In this case a detailed discussion of the full plan was sufficient to alert the subcontractor to the importance of following specifications as closely as possible. Constant or at least frequent attendance on-site by the general contractor or a knowledgable representative seems to be indispensable in such specialized construction, in which small deviations may have significant effects.

d) Effect of On-Site Pollution on Construction Personnel

Certain observations were made during the construction of Sunnyhill that may have an important bearing on general construction practice. Because of familiarity with the symptoms of chemical susceptibility, the author was aware of the general pollution conditions on site and their effect on himself, his immediate staff, and on the subcontracted work crews.

The predominant on-site pollutant was the exhaust from diesel and regular gasoline engines in bulldozers, delivery trucks, cranes, ready-mix trucks, backhoes, forklifts, cement mixers, and generators. For the most part subcontracted personnel seemed to be little affected by these exposures, although there was no way of properly comparing performance under polluted and non-polluted conditions.

The author experienced mild physical symptoms during such exposures, and also experienced increased difficulty in thinking. This effect was minimized by installing a chemisorbant filtration unit in the construction office trailer, and by the use by the author of a portable cannister of activated carbon when air quality was particularly bad.

One incident during the early stages of construction, though not definitive as proof of a problem, is suggestive that pollutant exposures may sometimes affect subcontractor performance. The concrete subcontractor who was hired to frame and pour the basement walls did excellent, precise work up to the time when the 335 cm. (11-foot) high forms had been erected around the exterior of the building outline. As the inside layer of forms was being prepared, one worker sprayed both interior form surfaces with an oil and gasoline mixture designed to make later removal of the forms easy.

This action took place on a hot, still day, and the air within the three-sided structure accumulated pollutants to the point that the author began to avoid the site because of adverse physical reactions. At the same time, the crew began to make framing mistakes for the first time, and periodic inspection revealed that several parts of the plan had been misread. Several areas were pulled apart and reconstructed until the structure met the original design specifications.

Other similar occasions (that could also have been only coincidence) suggested the possibility that pollution may have affected performance. Carefully designed studies to gauge the effect of transient pollution levels on motor co-ordination and mental performance will likely be required in order to resolve this question. While productivity and accurate performance of the task is important, the possible effect of pollution on construction safety should perhaps be given priority consideration in future studies.

In some of the interior finishing, the author has undertaken much of the work personally wherever testing of alternative methods has been necessary, e.g. in establishing the appropriate method for attaching the vapour barriers. On many occasions a portable air filtration device was necessary in order to preserve physical strength and mental problem-solving ability during exposures to bothersome materials (e.g. fiberglass insulation, polyethylene vapour barrier, fresh silicone caulking, propane soldering torch, etc.).

While the author may be in the minority as far as susceptibility to chemicals is concerned, it would appear likely that at least some minority of construction workers are likewise affected under similar and more severe exposures.

2.1.6 Effectiveness of Design

Full evaluation of the effectiveness of the various design features employed in the Sunnyhill example will have to await completion and perhaps many years of operation of the building.

However, the author has gained some understanding through observing the reaction of chemically sensitive persons to the building even in its unfinished state. Makeshift partitioning and temporary ducting have allowed a number of informal experiments. The following tentative lists are offered, though they reflect opinion only and are not based on hard data:

1) Features tentatively found to be very effective in minimizing indoor pollution in the Sunnyhill example

- location (away from major polluted areas)
- steel framing and concrete floor structure
- well-sealed aluminum foil vapour barrier
- central exhaust and deliberate venting through multiple inlets
- specific venting of problem appliances
- recirculating air through filters
- use of electric hot water heat source
- separation of air in different areas
- use of bedroom sanctuary concept
- exterior mounted central vacuum
- bare floors without wall-to-wall broadloom
- relatively bare furnishings
- unpainted plaster walls
- strictly enforced house rules against smoking and perfume

2) Features found to be less effective than hoped, or which yielded unexpected problems, but which were on balance helpful

- passive solar heat (problems arising centre on avoiding materials that gas off considerably when exposed to direct sunlight)
- filtration of intake air (activated carbon and chemisorbant filters adequate for multiple-pass air recirculation have been less successful in single-pass mode for removing wood smoke odours from intake air)

3) Features not tested sufficiently at this stage, but which appear promising

- extensive use of cupboards
- radiant hot water heat in ceiling panels
- venting of lighting fixtures into ceiling space
- separation of plaster walls from vapour barrier
- use of airtight cavity wall construction

4) **Materials found useful for interior surfaces for chemically susceptible persons:**

- glass
- ceramic tile
- plaster of paris
- steel
- portland cement concrete

5) **Materials found useful, but which may still cause problems for some extremely susceptible persons:**

- maple hardwood
- aluminum foil
- untreated cotton fabrics and padding

6) **Materials found to be more problematic than expected, but acceptable when properly sealed or vented to the exterior**

- rigid fiberglass cavity wall insulation, particularly when heated
- pink fiberglass bat insulation, particularly when heated
- polysulfide polymer rubber caulking
- polyethylene sheeting and tape
- exposed styrofoam insulation, particularly when heated (rejected for above-grade exterior or interior use, but accepted for below-grade exterior use)

7) **Features tested for Sunnyhill that are considered most acceptable for use in other buildings to be used primarily by chemically susceptible persons:**

- location away from major pollution sources
- carefully sealed foil vapour barrier
- deliberate intake air and general exhaust venting, (with appropriate heat exchange where possible)
- specific venting of problem appliances
- hot water heating (using clean interior heating source such as electric boiler, heat pump, or (with caution) an exterior fuel-fired boiler)
- particulate and gaseous pollutant filtration
- exterior-mounted central vacuum cleaner
- extensive use of cupboards
- bedroom sanctuary concept
- ceramic tile floor on mortar bed
- plaster walls

2.1.7 Ongoing Monitoring and Research

A number of features of the building will require extensive testing and monitoring before final conclusions can be reached as to their relative merits and economics. In some cases it is expected that the full potential of a technique will only be realized when it is coupled with a permanent computerized monitoring and control system.

a) Monitoring of indoor and outdoor pollutant concentrations

Regular measurements of common pollutants both indoors, outdoors adjacent to the building and in conventional buildings as controls, will be required to determine the extent to which the measures discussed in the previous section do in fact lower indoor pollution exposures.

Gases that should be monitored at least periodically include:

Carbon Monoxide (CO)
Carbon Dioxide (CO2)
Nitrogen oxides (NO, NO2)
Ozone (O3)
Sulfur Dioxide (SO2)
aliphatic hydrocarbons (e.g. isobutane)
aromatic hydrocarbons (e.g. toluene)
halogenated hydrocarbons (e.g. methylchloroform, vinyl chloride)
aldehydes (e.g. formaldehyde, acetaldehyde)
alcohols (e.g. ethanol)
ketones (e.g. acetone)
ethers (e.g. dimethylether)
esters (e.g. ethylacetate)
miscellaneous other organic compounds
radon and daughter elements

Particulate measures should include:

general particulates
aerosols
dust mites
specific mould and pollen concentrations

These can also be studied against variations in major environmental control variables within the building, including number of occupants, setting of intake and exhaust systems, extent of recirculation through chemisorbant filters, activities within the building, temperature and humidity, etc.

b) Development of automatic control systems for intake air, recirculation of indoor air and balance of exhaust system

In the long term, it is intended that experiments should be conducted to determine whether automatic monitoring and control of air quality through computer manipulation of the main air system variables would be advantageous. Some of the variables that could be controlled are:

- selective automatic dampering of exhaust vents
- control of total exhaust volume
- control of central and remote air intakes
- control of air recirculation through filters

The primary advantage to such control is energy conservation, since overall ventilation could in theory be kept to a minimum consistent with air quality needs. Unoccupied areas need not be ventilated as actively as occupied areas.

With the present manual system, two problems can and have occurred:

1. Total exhaust volume can be increased by adjusting the fan speed control. If individual vent dampers are not adjusted at the same time, venting everywhere is increased to accommodate an increased need for ventilation in one location. Since it is impractical to continually readjust dampers manually, the price is paid in energy loss through excess total ventilation.

2. Venting can be obtained at a specific location by opening a vent damper that was previously closed. While the resulting draw may be adequate for the one location, opening one vent without increasing the fan speed decreases draw throughout the remainder of the system, and may result in underventing in other areas.

c) Effectiveness of design for diagnosis and rehabilitation of persons with extreme chemical susceptibilities

It is expected that the ultimate test of the building's effectiveness will be provided by persons with extreme chemical susceptibilities who will use space in the clinical area under a physician's care. Based on the author's experience and the successful adaptation by the author's family to the interior environment even during the construction phase, the overall exposure levels are expected to be as low as or lower than those afforded by clinical facilities now in operation in the United States. The low-pollution conditions appear to have contributed to an overall decrease in susceptibility to chemical exposures in the author and his family, over a period of four years.

However, it is also to be expected that while many patients are likely to experience overall symptom relief in the relatively clean atmosphere, they will at the same time be able to detect easily any area within the building that is even slightly polluted. This kind of experience will be invaluable in determining sources of pollution and in modifying designs and material choices for application in other clinical and residential facilities for chemically susceptible persons.

Limited experiments have already been conducted in the low-pollution environment at Sunnyhill, involving clinical testing of inhalant, food and chemical antigens. So far the background contamination has been low enough that most symptoms evoked in test challenges are clearly distinguishable from other causes.

d) Testing of materials in the low-pollution environment

Because the various rooms of the building are separable from each other insofar as air flow is concerned, it will be possible (with some exceptions) to introduce specific building material samples into a test room and simulate the effect of that one material independent of other materials normally found in conventional housing. This should ideally complement laboratory testing of material samples in more confined volumes, to eliminate any interference from other materials and to establish baseline data as to the primary gas-off products from each material.

Having established primary gas-off products and predicted room levels of various pollutants under different ventilation conditions, the experiments could be extended by using chemically susceptible and non-chemically susceptible volunteers to test actual short-term exposure effects on humans.

2.2 APPLICATION TO CURRENT CONTRUCTION PRACTICE

2.2.1 Evidence of Need

The Sunnyhill Low-Pollution Centre represents the most stringent end of a full spectrum of air quality standards and needs. The standard being sought at Sunnyhill is neither practical nor necessary for general application in conventional housing in Canada at the present time.

However, the potential indoor air pollution problems documented in section 1 and discussed in section 2 indicate that the housing industry in Canada may have to move slowly and carefully toward taking indoor air quality into account in design decisions and construction practice. The need for concern has been established; a complete set of specific standards and guidelines has not.

Evidence cited in section 1 suggests the need for Canadian industry to respond at the present time to the following problems:

1) **Meeting Standards**

Existing and new construction should not allow buildup of pollutants in indoor air to exceed present accepted standards or guidelines (refer to section 1.5 for accepted levels of pollutants found indoors).

There is a need for more guidelines applicable specifically to residential situations.

2) **Providing a Margin of Safety**

Pollutants commonly found in homes have with few exceptions not been fully tested for long-term health effects and the potential for sensitization to other chemicals, at low levels of exposure to individual pollutants. Nor have health effects of common mixes of pollutants been tested properly.

It is reasonable to expect that Canadian housing should provide some margin of safety to allow for the possibility that at least some of the common pollutants will later be discovered to have a potential for provoking illness.

3) **Allowing Individuals Some Choice**

Some persons are either at greater risk of experiencing health problems or are already experiencing health problems relating to indoor exposures. These persons require clean indoor air. Others with no known risk factors may wish to choose air quality standards themselves.

Canadian housing technology should provide some flexibility for adapting conventional housing to at least a limited range of optional air quality standards (e.g. by allowing some occupant control of ventilation or material choices).

4) **Providing for Specialized Needs**

There is now a small but growing population of chemically susceptible persons for whom average residential air quality standards are totally inadequate.

Technology and facilities necessary to meet the specialized needs of such persons should be developed, just as they have been for other physical handicaps. The extent to which the majority of buildings should also accomodate such specialized needs is not an easy question and should be analyzed in detail as more medical evidence is developed.

Section 3 following will make specific recommendations regarding further studies and action in each of these and other areas. For the purpose of the present discussion, however, it is important to establish that despite many gaps in medical information, there is a basic need in Canada for the housing industry to understand:

- common causes of indoor air pollution in present homes and modern construction practice
- feasible methods of reducing or avoiding residential indoor air pollution problems.

The Sunnyhill project has provided some experience in both of these areas. The application of this experience to current design and construction practice is discussed in the following sections.

2.2.2 Problem Materials and Designs

This section contains a summary listing of problem materials, appliances and design features in conventional housing, that are considered by the author to be primary causes of indoor air pollution in Canadian housing. The listing is judgmental, based both on the evidence presented in Section 1 of this report, and on the author's experience with the effects of indoor pollutants on the health of chemically susceptible persons.

The inclusion of an item in the following list is meant to suggest only that its contribution to indoor air pollution should be examined in more detail, and is not in any way a recommendation at this time that such materials

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or practices are not acceptable in general use:

- installation of gas furnaces without proper installation of chimney liners
- leaky or improperly adjusted fossil fuel furnaces and fuel tanks
- unvented gas stoves
- unvented kerosene or gas heaters
- unsealed chipboard, in furniture, cupboards or subflooring
- synthetic carpeting that releases formaldehyde
- homes with a built-in or attached automobile garage
- super-sealed/super-insulated homes, with 1/2 air change per hour or less, and which also contain numerous interior pollutant sources or activities (e.g. synthetic carpet, smoking).
- all unsealed foam insulation materials other than urea-formaldehyde foam insulation*, particularly when used in applications where they will be exposed to considerable heat, e.g. in exterior cladding.
- cellulose insulation in homes with substantial air transfer from the attic space to rooms below.
- fiberglass insulation in homes with substantial air transfer through walls and from attic to rooms below, and where inadequate attic venting allows considerable heating of the attic space.
- foam furniture padding and various chemical upholstery treatments, including fire retardants

Certain occupant activities and household products also contribute strongly to indoor air pollution and need to be examined more carefully:

- use of pesticides
- tobacco smoking
- use of scented volatile cleaning fluids and aerosols
- indoor storage of volatile and poisonous products

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* Urea-formaldehyde foam insulation has already been banned from further residential use in Canada.

2.2.3 Energy Conservation

Section 1 has reviewed some of the indoor air quality hazards associated with energy conservation measures. Some of these are also included in the summary list in the previous section.

The discussion below outlines ways in which energy conservation measures can be introduced without bringing on major indoor air quality problems. It is desirable that further research on indoor air technology and on energy conservation be closely co-ordinated.

a) Addition of foam, cellulose, fiberglass or other insulation in homes where there is considerable air transfer between insulated spaces and living spaces.

Early outgassing of these insulation materials should be inhibited from entering living spaces by the addition of a complete air/vapour barrier and adequate attic space ventilation.

(Urea-formaldehyde foam has been banned for residential use in both Canada and the United States and therefore is not recommended even with such precautions. It is interesting to note, however, that UFFI does not appear to have caused as many problems in Europe, due to its use in exterior cavities that are sealed from the living spaces and vented to the exterior.)

b) Addition of caulking and other sealing materials into living spaces.

Some materials using for sealing and weatherstripping contain volatile compounds that gas out for a considerable time. Choosing the least odourous material and testing chosen materials against the possible chemical sensitivities of house occupants will reduce potential problems. In some cases materials may prove acceptable if they in turn can be sealed with a more acceptable material, such as aluminum tape.

c) Super-sealing the building envelope.

This technique has been criticized as being a cause of indoor air pollution. It is in fact a desirable practice even in specialized low-pollution dwellings and is not a direct cause of indoor air pollution other than by means of the materials used to acomplish the seal.

However, when a building is 'tightened up' without introducing deliberate ventilation, air pollutants from other sources within the home can build up. Whenever air infiltration is reduced, consideration should be given to the addition of deliberate ventilation, preferably with a heat exchanger, and to the reduction of interior pollution sources.

d) Installation of air solar heating systems

Some solar heating systems, both active and passive, have contributed to an increase in indoor air pollution. Commonly they involve air flows in which air is drawn over hot painted surfaces or through areas with high mould levels (e.g. greenhouse or some rock storage beds).

Filtration of air, substitution of materials, and use of heat exchangers should be analyzed as possible means of reducing gaseous pollution and mould circulation. Individuals with inhalant or chemical sensitivities should be particularly careful to investigate proposed systems fully before installing.

2.2.4 Adaptable Techniques

The following is a short list of low-pollution materials and techniques seen by the author as most immediately adaptable for use in either new or retrofit conventional housing:

- deliberate ventilation and use of heat exchangers
- specific venting of appliances including gas and electric ranges, microwave ovens, televisions and other electronic equipment
- regular inspection and maintenance of all fossil-fuel or wood-burning furnaces
- careful sealing of air/vapour barriers to avoid infiltration of air through insulating and building cladding materials
- avoidance of high gas-off construction materials such as chipboard, unless adequately factory-sealed, e.g. in laminated shelving.
- reduction of high gas-off furnishings and materials (e.g. less use of synthetic carpeting, foam padded furnishings and soft plastic products)
- reduced use and/or storage of volatile compounds in the home (e.g. cleaning fluids, pesticides, and household aerosols)
- provision for optional addition of gaseous and particulate filtration of indoor air by the individual homeowner
- education of housing consumers to recognize building-related health problems and to be able to test proposed building materials against occupant sensitivities.

2.2.5 Cost Implications

None of the methods listed above except indoor air filtration involve significant additional costs over what would normally be spent for energy conservation purposes in new housing (assuming that some effort would already have been made to introduce deliberate ventilation at least to a standard of 1/2 air change per hour, with heat exchange).

Areas where additional costs should be evaluated in more detail are:

- extra fan and duct capacity to allow (at the homeowner's option) higher air change rates.
- the increased cost in energy for additional ventilation
- equipment cost and energy savings for heat exchangers
- new housing and renovation costs of introducing additional local ventilation outlets and fans, similar to present bathroom installations
- additional labour and materials to add a complete vapour barrier separating attic space from living space in home renovations; additional labour and supervision to ensure complete seal on all other vapour barrier installations
- differences in cost, plus or minus, in choosing low gas-off materials and furnishings (e.g. kitchen cupboards)
- cost of external storage, e.g. garage shelving, remote utility sheds, for volatile and poisonous materials.
- purchase cost and annual operating costs of gaseous and particulate filtration systems for recirculating indoor air

In the short term, while research into potential problems and effective technology continues, and while debate continues on the standards of air quality that are desirable, it is likely that the housing industry in Canada will respond most strongly to indoor air pollution problems with those measures:

1. that do not significantly increase construction costs, and/or
2. which are installed or operated only at the option of the individual homeowner.

For example, variable controls on ventilation fans would allow the homeowner the freedom to conserve or ventilate, depending on activities within the building.

PART 3: RECOMMENDATIONS

The following recommendations are intended to provide an initial framework for discussion among government agencies, the housing industry, and the building trades. They outline what needs to be done, but not who should do it. The latter is a question for later discussions among all affected parties. The interdisciplinary nature of the problem combined with present policies of restraint make it most likely that joint endeavours will be the most efficient.

The basic strategy proposed is fourfold:

A. Short-circuit major potential hazards such as badly-installed or poorly ventilated indoor combustion equipment before more deaths and health damage occur.

A1 It is clear that there are a number of immediate indoor air hazards that will contribute to increased illness and possibly deaths if they are not addressed as quickly as possible. These include:

- gas furnaces installed without proper chimney linings (leading to breakdown of mortar, chimney blockage, and carbon monoxide poisoning)
- use of unvented gas or kerosene-fired space heaters in areas with low air exchange rates (producing high levels of carbon monoxide)
- use of significant quantities of unsealed particleboard in areas with low air exchange rates (producing high levels of formaldehyde)

An organized inter-agency approach to immediate indoor air quality hazards should be set up so that all affected Canadians can be properly alerted and instructed as to proper precautions.

B. Begin to deal with the specialized housing needs of those already badly affected by indoor pollution.

B1 There is a small but significant population of Canadians who are now adversely affected by indoor air pollution, and who need specialized housing or additional facilities to retrofit existing housing. Research is needed to identify in detail the number, characteristics, needs, and locations of this new handicapped population. A feasibility study is required to determine the need, the type, the best locations, and the appropriate distribution of responsibilities for developing specialized low-pollution housing.

B2 Prototype designs for suitable housing units (both single and multiple-family dwellings) which address the problem of chemical and other environmental susceptibilities should be prepared, tested, and published.

B3 There is an urgent need for testing and rehabilitation facilities for persons affected by low-level chemical exposures. The groundwork for such facilities has been laid but funding is needed.

B4 There is a demand for detailed lists, including brand names, of all building materials that are suitable for use by chemically susceptible persons, as well as lists of materials they should avoid. A research and testing program is required. The results will be particularly useful to UFFI homeowners with health problems.

C. Help everyone involved to catch up to the present state of knowledge of indoor air pollution, and encourage the immediate introduction of known design techniques for reducing indoor air pollution.

C1 The field of indoor air pollution research is advancing quickly, and the time and expense of keeping up is beyond the capability of most private corporations, professionals or other individuals.

Some resources must be focussed on maintaining research contacts internationally not only to gather information but to help determine what research role Canada can best play. A who's who in the field should be prepared and made accessible to the building industry and to the appropriate scientific communities.

C2 An organized and accessible computerized information base of research and design information is needed, to avoid unnecessary duplication of effort. This should be made interactive so that up-to-the-minute experience can be shared among all agencies involved.

C3 A forum is needed for efficient communication among all major agencies and interests dealing with indoor air pollution, including those influencing housing changes that affect indoor air pollution (e.g. energy conservation).

C4 An ongoing program to 'distill' research in this field into a form understandable and useful at the practical level (building design and construction) should be undertaken.

C5 As much information as possible on indoor air pollution problems and solutions should be made publicly available in lay terms, so that individual Canadians can recognize and address problems by themselves whenever possible. Priority should be placed on the most immediate or significant problems which are not already dealt with by special alert programs. Examples include:

- pollutant exposures from badly-ventilated gas stoves,
- hazards in the use of unvented kerosene heaters
- exposure to radon gas
- tobacco smoking with inadequate ventilation
- heavy use of household chemicals and pesticides.

C6 Effort should be made to encourage the incorporation of low-pollution design techniques into normal building design and construction. The most likely techiques to gain early acceptance are those which do not necessarily involve major costs or tradeoffs or those in which the cost of operation is optional to the consumer. Examples include:

- o using materials that have low gassing-off properties
- o variable control heat exchanger fan
- o optional furnace filter system.

D. Embark on an organized long-term program of design and health research, while opening discussions on regulatory and other means for assuring clean indoor air for Canadians.

D1 Proper long-term recommendations for ensuring that Canada's housing stock fully addresses the indoor air pollution problem will require much more detailed knowledge of the problem and development of a new generation of design technology.

Further design studies will be necessary to propose and test low-pollution housing components, including materials, assemblies (e.g. insulated walls), heating and ventilating systems, and air filtration devices. An organized science of low-pollution design should emerge from this effort.

D2 Practical methods of monitoring indoor air quality levels are needed, particularly methods and devices that can be used on a regular basis by the householder directly.

D3 Research and development of feedback controls on environmental systems, based on some form of air quality monitoring, is needed in order to design systems that will in the long term assure air quality without householder intervention being required.

D4 Much additional detailed medical health research is required in order to answer the many questions yet unanswered concerning the effects of low levels of environmental pollutants on people. The major areas are:

a) the effects of exposure to indoor air pollutants at commonly encountered levels over long periods of time

b) the development of proper low-pollution research and clinical facilities in which subjects can be tested and in which diagnosis of air-pollution related health effects can be done.

c) determination of the proportion of the population who are presently affected adversely by indoor pollution exposures, and the proportion who may be presently unaffected but are at greater risk of health damage than most

D5 In order to make competent decisions on the long term trade-off between health, energy, economic, and social factors, research will be needed to estimate the nature and amount of social and economic cost to Canada of indoor air pollution.

D6 Throughout such an organized research program, it will be necessary for all agencies whose actions affect or could affect indoor air quality in Canada to get together and open discussions on the most feasible long-term means for assuring Canadians the right to have clean indoor air. Since the problem is complex, it is likely that a mix of private sector actions and government regulations on building materials, consumer products, and building codes will be required.

Keyword Summary of Recommendations

A. SHORT-CIRCUIT MAJOR POTENTIAL HAZARDS

A1. Organize inter-agency approach to alert Canadians to:

1) unlined chimneys with gas furnaces
2) unvented kerosene space heaters
3) unsealed particleboard
4) other major indoor pollution hazards

B. DEAL WITH LOW-POLLUTION HOUSING NEEDS

B1. Study need for low-pollution housing
B2. Develop prototype 'clean' housing designs
B3. Foster diagnosis and rehabilitation facilities
B4. Develop practical list of building materials

C. SPREAD AND APPLY PRESENT KNOWLEDGE

C1. Develop research contacts and produce 'who's who'
C2. Organize an accessible information base
C3. Establish an interagency forum for discussion
C4. 'Distill' research for practical application
C5. Prepare public information in lay terms
C6. Encourage introduction of low-pollution design

D. FOSTER MORE RESEARCH AND DISCUSSIONS ON REGULATION

D1. Undertake studies in low-pollution design
D2. Develop practical air quality monitoring devices
D3. Develop air quality feedback control systems
D4. Fund health research on indoor pollution effects
D5. Study socioeconomic costs of indoor air pollution
D6. Study regulatory and other control options

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APPENDIX 2: CONFERENCES AND MEETINGS CITED

The following list of conferences and meetings has been taken from the references cited in Appendix 1: Full Bibliography. It is not intended to be a complete list, but rather only a representative list of gatherings at which either indoor air pollution was discussed as part of another theme, or at which indoor air pollution was the major topic of discussion. The number of such gatherings since 1975 indicates a rapidly growing international interest in the subject.

November 5-7, 1975
16th Annual Meeting of the Japan Society of Air Pollution,
Niigata, Japan

July 11-16, 1976
6th Congress of the International Ergonomics Association

May 16, 1977
International Clean Air Congress
Tokyo, Japan

August 22-24, 1977
Environmental Aspects of N-nitroso Compounds - A Working Conference
Durham, New Hampshire, USA

April 23-28, 1978
Natural Radiation Environment III
Houston, Texas, USA

April 25-28, 1978
13th International Colloquium on Polluted Atmospheres
Paris, France

June, 1978
Increased Human Susceptibility to Environmental and Occupational Pollutants
Environmental Protection Agency, U.S.
University of Amherst, Amherst, Massachusetts

June 25-30, 1978
Energy Conservation: Predicting Indoor Air Quality
Air Pollution Control Association Annual Meeting
Houston, Texas, USA

August 30-September 1, 1978
Comfort, Performance, and Health in Residential, Commercial, and Light-Industry Buildings - First International Indoor Climate Symposium,
Danish Building Research Institute, Copenhagen, Denmark

January 1979
ASHRAE Symposium on Air Infiltration
Philadelphia, PA, USA

January 23-25, 1979
Technology and Energy Conservation: 3rd National Conference
Tucson, Arizona

April 2-3, 1979
Symposium on Aerosol Generation and Exposure Facilities
Honolulu, Hawaii, USA

April 3-6, 1979
Health Aspects Related to Indoor Air Quality
WHO Working Group
Bilthoven

May 27, 1979
International CIB Symposium on Energy Conservation
in the Built Environment
Copenhagen, Denmark

June 24, 1979
Annual Air Pollution Control Association Meeting
Cincinnati, Ohio, USA

May 27, 1979
International CIB Symposium on Energy Conservation
in the Built Environment
Copenhagen, Denmark

September 10, 1979
American Chemical Society National Meeting
Washington, D.C., USA

October 22-26, 1979
International Conference on Energy Use Management,
Los Angeles, California, USA

December 3, 1979
Conference on Thermal Performance of the Exterior Envelopes
of Buildings
Orlando, Florida, USA

March 3-7, 1980
Radon Specialist Meeting
Rome, Italy

May 12-16, 1980
Building Energy Management: Conventional and Solar Approaches
Proceedings of the International Congress
Povoa de Varzim, Portugal

June 1980
Air Pollution Control Association Annual Meeting
Montreal, Canada

August 24-29, 1980
American Chemical Society 180th Annual Meeting
San Francisco, California, USA

December 3-5, 1980
Health Hazards in the General Community: Workshop on Indoor Air Quality Research Needs
Interagency Research Group on Indoor Air Quality, U.S. EPA
Leesburg, Virginia, USA

March 17th, 1981
Annual Energy Conservation Management Conference
Portland, Oregon, USA

April 1981
2nd European Conference on Building Materials
Glasgow, Scotland

April 6, 1981
International Energy Agency (IEA) Conference on New Energy Conservation Technologies and Their Commercialization
Berlin, Germany

May 28-29, 1981
Symposium on Health Aspects of Indoor Air Pollution
Committee on Public Health, New York Academy of Medicine
New York, New York, USA

June 21, 1981
Annual Meeting of the Air Pollution Control Association
Philadelphia, Pennsylvania, USA

September 28, 1981
International Gas Research Conference
Los Angeles, California, USA

October 13-16, 1981
International Symposium on Indoor Air Pollution, Health and Energy Conservation
Amherst, Massachusetts, USA

March 3-4, 1982
National Conference on Formaldehyde and Building-Related Illness
Department of Natural Resources, Ball State University
Indianapolis, Indiana

May 4, 1982
Formaldehyde, the Facts: Corpus Forum
Toronto, Canada

June 7-11, 1982
Occupational Health and Safety Workshop Program
College of Cape Breton
Sydney, Nova Scotia, Canada

June 9-12, 1982
Assessing and Monitoring Indoor Air Pollutants
WHO Working Group
Nordlingen, Federal Republic of Germany

June 27-30, 1982
ASHRAE 1982 Annual Meeting
Toronto, Canada

July 21-23, 1982
Health Significance of Formaldehyde in Homes with Urea-formaldehyde Foam Insulation
WHO Planning Meeting
Copenhagen, Denmark

August 23-25, 1982
Second International Symposium on Epidemiology in Occupational Health
Montreal, Canada

October 3-8, 1982
Sixteenth Advanced Seminar in Clinical Ecology
Banff, Alberta, Canada

Index of Names

ACGIH, 10, 39, 65, 227
Alanko, K, 227
Algar, RA, 245
Alger, C, 231
Allara, DL, 110, 227
Allen, JR, 256
Alter, HW, 16, 227
Alzona, J, 227
American Conference of Governmental Industrial Hygienists (see ACGIH)
American Soc. of Heating, Refrigerating & Air Conditioning Engineers (see ASHRAE)
Anaclerio, RN, 243
Andersen, IB, 227
Anthon, DW, 243
Apte, MG, 153, 256
Aranow, WS, 227
Armet, DB, 242
Aronow, 39
ASHRAE, 48, 55-57, 153, 227
Assendelft, AV, 56, 119, 227
Associate Committee on the National Building Code, 153, 227
Atomic Energy Control Board of Canada, 15
Axelson, O, 228
Bachand, RT, 255
Barden, JD, 258
Baretto, ED, 255
Barker, RH, 110, 228
Barnes, JM, 86, 228
Barton, SC, 20, 28, 114, 228
Beall, JL, 67, 73, 81, 228
Beard, JH, 245
Beck, GJ, 229
Bedi, JF, 236
Bell, IR, 71, 94, 250
Bellin, P, 228
Benarie, M, 228
Benson, FB, 228
Bergin, EG, 228
Berglund, LG, 231, 242
Berk, JV, 130, 135, 137, 228, 229, 231, 238, 239, 251, 259
Bernstein, RS, 60, 62, 229
Biersteker, K, 234, 242
Binder, RE, 229
Birenzvige, A, 9, 10, 36, 37, 63, 103, 104, 230
Bishop, YMM, 235, 254
Bock, FG, 229
Boegel, ML, 239, 243, 251
Boleij, JSM, 234, 242
Bonham, GS, 38, 39, 229
Bouhuys, A, 229
Boylen, G, 238
Brahim, SA, 125, 249
Brasser, LJ, 114, 232
Bravery, AF, 52-54, 229
Breisacher, P, 237
Brethauer, R, 232
Bridbord, K, 58, 137, 230
Bridge, DP, 37, 230
Briggs, TM, 230
Brookman, ET, 9, 10, 36, 37, , 63, 103, 104, 230
Brooks, AGF, 245
Brown, EA, 230
Brown, SR, 130, 229, 239
Brubaker, PE, 230
Brundrett, GW, 52, 54-56, 92, 119, 230
Brunekreef, B, 234, 242
Brunneman, KD, 230
Bruno, RC, 15, 230
Buckley, RD, 31, 230
Budiansky, S, 231
Budnitz, RJ, 14, 16, 17, 105, 231, 238
Building Research Establishment, 231
Burge, PS, 249
Burton, RM, 247
Buscher, D, 124, 231
Butcher, B, 258
Butler, J, 256
Butler, JR, 67, 231
Cain, WS, 110, 138, 153, 231, 242
Calabrese, EJ, 11, 29, 31, 32, 40, 61, 77, 88, 90-92, 94, 98, 124, 231, 232
Caldwell, DE, 228
California Department of Consumer Affairs, 5, 34, 59, 66, 71, 73, 89, 93, 100, 113, 116, 117, 124, 145, 232
Carhart, HW, 110, 144, 258
Carnow, BW, 40, 92, 232
Carnow, V, 40, 92, 232

Case, GD, 238
Castegnaro, M, 230
Centre de Toxicologie du Quebec, 87
Chemical Industry Institute of Toxicology, 44
Cheng, JT, 238
Chester, EH, 232
Chinn, S, 245
Chuong, BT, 228
Clark, D, 245
Clark, K, 230
Clarkson, TW, 232
Cleland, JG
Cliff, KD, 245
Clink, WL, 10, 259
Coburn, RF, 11, 232
Cohen, BL, 227
Colley, JRT, 114, 232
Colligan, MJ, 232
Collins, R, 253
Colombo, NJ, 230
Colome, S, 235
Committee on Public Health, New York Academy of Medicine, 232
Comstock, GW, 238
Conright, KL, 242
Consumer Product Safety Commission, U.S., 33
Consumers Union, 107, 233
Cooper, WC, 90, 233
Corn, M, 37, 230
Correy, P, 253
Cote, RW, 241
Cote, WA, 10, 20, 21, 103, 233, 257, 259
Couch, RB, 55, 233
Cox, RA, 142, 233
Craighead, IB, 245
Craigmill, A, 257
Crawshaw, GH, 142, 233
Culot, MVJ, 233
Cummins, LH, 242
Davies, BL, 245
DeBias, DA, 12, 233
DeFrees, JA, 249
Decher, R, 246
Dehne, S, 252
Delehunt, JC, 236
Demas, P, 117, 131, 233
Dement, JM, 233
Department of Energy, Mines and Resources, Canada, 102
Department of Energy, USA, 233
Depaso, D, 255
Derham, RL, 234
Desmond, RM, 249
Devitt, TW, 230
Dharmarajan. V, 258
Diamond, P, 256
Dickey, 32
Dickinson, JB, 249
Diem, JE, 258
Diemel, JAL, 234
Dillworth, JF, 153, 239, 256
Dimich, H, 255
Dimmick, RL, 234
Dmitriev, MT, 259
Dockery, DW, 234, 235, 254
Doris, CI, 53, 149, 234
Dougherty, RC, 236, 242
Dudney, CS, 5, 234
Duel, WC, 88, 235-238, 240, 259
Duffee, RA, 231
Dukick, A, 257
Dunhill, A, 252
Durfee, RL, 258
Dutch Public Health Council, 19, 21
Edgar, RT, 250
Edling, C, 228
Ellis, EF, 240, 245
Elmes, PC, 234
Engebtretson, GR, 234
Environmental Protection Agency, U.S., 10, 11, 12, 19, 27, 48, 64, 77, 90, 105, 111, 122, 234
Evans, MJ, 234
Expert Advisory Committee to the Department of National Health and Welfare, Canada, 44
Fairbairn, AS, 234
Faist, AP, 235, 257
Fanger, PO, 235, 243, 246
Fanning, LZ, 243, 245
Farrell, BP, 235
Fawcett, IW, 249
Feingold, M, 238
Fenvyes, EJ, 250, 254
Fernandes, WdeO, 235, 257
Ferrand, EF, 235
Ferris, BG, 235, 243, 254

Finkel, AJ, 73, 88, 111, 259, 235-238, 240
Finkel, JM, 235
Fischer, A, 257
Fisk, WJ, 235, 249
Fitzgerald, JE, 235
Flaschbart, 9
Fleischer, RL, 14, 16, 235
Fleming, GM, 232
Florey, CduV, 22, 23, 236, 245
Folinsbee, LJ, 236
Foote, RS, 122, 236
Forsen, K-O, 227
Forster, RE, 232
Freeman, BA, 247
Freeman, G, 31, 234
French, JG, 230
Friedman, M, 58, 59, 236
Froeb, HF, 40, 258
Frohliger, JO, 227
Frost and Sullivan, 124, 236
Funabashi, S, 259
Gallup, J, 242
Gannon, R, 259
Gay, B, 230
General Accounting Office, U.S., 5, 236
General Service Administration, U.S., 15
Geomet, Inc, 236
Gerblich, AA, 232
Gillman, SA, 242
Girman, JR, 18, 37, 40, 236, 249, 256
Glindmeyer, H, 258
Godin, V, 228
Godish, T, 69, 236
Goldsmith, JR, 11, 238
Goldstein, E, 24, 236
Goldstein, BD, 236, 245
Gonzalea, MG, 242
Gordon, J, 236
Gosselin, RE, 70, 77, 115, 120, 121, 236
Grandjean, E, 257
Gravesen, S, 243
Green, GM, 87, 236
Greenberg, M, 250
Greenwood, DR, 237
Griciute, L, 230
Griffin, HE, 11, 237
Grimsrud, DT, 137, 249
Guimond, RJ, 235
Gunter, BJ, 237
Gupta, KC, 257
Hacker, AD, 247
Hackney, JD, 9, 11, 12, 30, 230, 237
Hadley, J, 237
Hagopian, JH, 259
Hake, CL, 116, 255
Hall, SK, 257
Halpern, M, 237
Halsey, HL, 251
Hamilton, RB, 122, 254
Hammer, DJ, 86, 237
Harke, H-P, 237
Harley, JH, 237
Harper, MG, 53, 149, 234
Harries, MG, 249
Hartle, R, 237
Hartley, R, 245
Hattori, H, 37, 237
Hayes, CG, 237
Hazardous Products Review Board, 67
Health and Welfare Canada, 37, 41, 42
Hedley, WH, 238
Heitner, KL, 252
Helsing, KJ, 238
Henderson, JJ, 228
Henkin, RI, 13, 22, 26, 28, 29, 45, 48, 49, 66, 68, 71, 238
Henschel, AF, 256
Hensel, EG, 256
Herrmann, AA, 255
Hexter, AC, 11, 238
Higuchi, E, 244
Hinds, WC, 37, 238
Hinkle, LE, 238
Hirschman, SZ, 121, 238
Hoegg, UR, 238
Hoffman, D, 113, 230, 237, 258
Holcomb, ML, 238
Hollowell, CD, 5, 6, 9, 10, 13-20, 23, 24, 26, 27, 29, 42, 43, 45, 47, 60, 68, 72, 73, 74, 78, 80, 83, 103-106, 108, 112, 115, 126, 126, 130, 135-137, 143-146, 148, 149, 151, 153, 154, 228, 229, 231, 235, 238, 239, 243, 245, 249, 251, 256, 259
Horowitz, J, 232
Horvath, SM, 236

Hosein, HR, 229, 253
Hosko, MJ, 255
Howell, TC, 244
Hoyle, ER, 259
Huey, RJ, 231
Huff, PJ, 257
Huggins, HA, 121, 239
Hughes, JP, 48, 68, 250
Hunt, CM, 239
Hunter, PA, 245
Hussain, MZ, 247
Imperato, PJ, 239
Inculet, II, 242
Instituut voor Milieuhygiene, Netherlands, 69, 239
Ishizaka, K, 240
Ishizaka, T, 240
Ishizu, Y, 240
Isseroff, R, 231, 242
Jaeger, RJ, 240
Jaffe, LS, 30, 240
Jakab, GJ, 57, 240
James, RH, 235
Johansson, I, 72, 74, 126, 240
John, HH, 245
Johnson, AR, 28, 31, 131, 231, 254
Johnson, AE, 250
Johnson, BL, 240
Johnson, JL, 250
Johnson, LV, 234
Johnson, TC, 233
Johnson, W, 233
Johnston, JW, 117, 257
Jonassen, N, 17, 135, 149, 151, 240, 241, 245
Jones, CR, 65, 243
Joselow, MM, 121, 241
Jow, HN, 227
Kalita, DK, 250
Kametani, K, 244
Kane, PB, 232
Kang, H, 257
Kaplan, SD, 241
Kats, G, 256
Kawahara, BL, 256
Kawakami, H, 244
Kawarabayashi, T, 241
Keefe, TJ, 252
Keller, MD, 241
Kerr, HD, 235
Kerrebijn, KF, 241
Keskinen, H, 227
Key, MM, 256
Khattak, MN, 258
Kingsbury, GL
Kjaer, J, 121, 257
Kling, H, 228
Knight, ME, 57, 240
Kobayashi, D, 255
Kobayashi, Y, 256
Koonce, JF, 239
Korsgaard, J, 50, 130, 131, 241, 242
Kothari, A, 230
Kozak, PP, 54, 242
Kriess, K, 115, 242
Krinkel, DL, 249
Kudryavtseva, GA, 257
Kuehl, DW, 242
Kulle, TJ, 235, 241
Kundson, R, 242
Kusuda, T, 242
Lagerwerff, JM, 31, 242
Lanese, RR, 241
Laseter, JL, 231
Lawrence Berkeley Laboratory, 5, 10, 13, 17, 24, 63, 242
Leaderer, BP, 153, 231, 242
Lebowitz, MD, 242
Lebret, E, 21, 242
Lee, L-Y, 31, 247
Lee, SD, 230, 242, 247
Lefcoe, NM, 242
Lepman, SR, 243
Letourneau, EG, 244
Letz, R, 243
Lewis, TR, 240
Lewis, WA, 238
Ligo, RN, 256
Lillie, TH, 64-67, 243
Lin, CI, 43, 228, 229, 238, 243
Linn, WS, 237
Lints, MC, 249
Lipinski, E, 96, 243
Lipmann, M, 106, 126, 243
Lipsitt, ED, 231
Livingston, JM, 65, 243
Lopez de Victoria, A, 254
Lowenstein, H, 50, 51, 53, 132, 243
Lowrey, AH, 251
Lundqvist, GR, 40, 41, 135, 227, 243

Lyle, RE, 230
MacLeod, KE, 74, 77, 79, 82, 243, 244
Mal'tsev, VV, 257
Mansmann, HC, 51, 244
Marceleno, T, 244
Marple, VA, 58, 244
Martinez-Catinchi, FL, 232
Mathews, KP, 51, 126, 244
Matsumura, T, 244
Matthews, TG, 244
McCarthy, S, 70, 115, 244
McCormick, RJ, 238
McCullough, RS, 244
McDonald, EW, 232
McFadden, JE, 245, 247
McGregor, RC, 15, 244
McIlhany, ML, 241
McIntyre, DA, 245
McLaughlin, JP, 17, 240, 245
Melia, RJW, 22, 23, 236, 245
Meyer, CB, 245
Meyer, MB, 238
Michaelson, GS, 55, 245, 250
Middleton, E, 240, 245
Miksch, RR, 42, 43, 72-74, 78, 80, 83, 115, 143, 148, 239, 243, 245
Miles, JCH, 150, 245
Miller, ER, 246
Miller, HC, 235
Miller, MS, 237
Ministry of Health, Ontario, 246
Mintz, S, 253
Mishchikhin, VA, 259
Mitchell, CA, 229
Mitchell, RI, 241
Mogro-Campero, A, 235
Mohler, JG, 237
Mohr, 109, 136
Mohr, M, 246
Molhave, L, 74, 78, 227, 246
Moller, J, 78, 246
Morgan, J, 67, 246
Moriates, S, 235
Morris, DL, 46, 53, 149, 246
Morris, JEW, 234
Morse, SS, 246, 247
Moschandreas, DJ, 60, 62, 109, 245-247
Motomiya, K, 259
Moulton, DG, 257
Mourmans, ARM, 241
Mudd, JB, 31, 247
Muittari, A, 51, 247
Muramatsu, S, 244
Murray, SH, 238
Mustafa, MG, 22, 30, 31, 247
Nadel, JA, 31, 247
Nakata, H, 241
Nantel, 87
National Aeronautics and Space Administration, U.S., 248
National Academy of Sciences, U.S., 38, 65, 248
National Institute of Occupational Safety and Health , U.S. (see NIOSH)
National Research Council, U.S., 5, 9, 10, 13-15, 17, 18, 22, 26, 27, 29, 33, 34, 36, 37, 42, 44, 45, 47, 48, 52, 55-57, 60-62, 73, 77, 79, 98, 131, 132, 248
National Technical Information Service, USA, 248
Natusch, DFS, 254
Nazaroff, WW, 14, 16, 17, 231, 239, 249
Nelson, JW, 247, 258
Nelson, SR, 236
Nero, AV, 16, 17, 231, 249
Newball, HH, 125, 249
Newman-Taylor, AJ, 249
Newton, A, 245
Nielsen, PA, 121, 257
NIOSH, 33, 34, 74, 77. 116, 248
NIOSH, and epoxy, 123
Nonat, A, 228
O'Brien, IM, 249
Occupational Safety and Health Administration (see OSHA)
Offerman, FJ, 138, 144, 249
Olishefski, J, 8, 97, 249
Olson, HG, 233
Olson, WC, 249
Olver, P, 253
Ontario Chimney Sweeps Association, 102
Ontario Ministry of Health, 44, 45, 246
Ontario Ministry of Consumer and Commercial Relations, 102
Orthoefer, DVM, 240

OSHA (U.S.), 10, 19, 27, 34, 48, 61, 77, 78, 80, 83
Ospital, JJ, 247
Ott, 9
Overstreet, M, 230
Palmero, A, 46, 249
Pedersen, EE, 237
Pelton, DJ, 247
Pepper, JH, 228, 229, 259
Pepys, J, 83, 88, 249, 249
Persily, A, 135, 249
Petering, DA, 28, 249
Peterson, G, 234
Peterson, JE, 255
Philpott, WH, 94, 250
Pipes, DM, 39, 250
Plenkett, S, 142, 233
Polite, E, 251
Posin, C, 230
Proctor, DF, 48, 68, 227, 250
Proctor, NH, 250
Raab, KH, 149, 150, 250
Radiation Policy Council, USA, 250
Rainer, D, 250
Rajagopalan, KV, 28, 250
Raloff, J, 9, 250
Randolph, TG, 93, 96, 117, 250
Random House, 52
Rea, WJ, 45, 71, 93, 94, 231, 250, 254
Rector, HE, 247
Reed, CE, 240, 245, 251
Reid, DD, 234
Reinhardt, CF, 93, 251
Repace, JL, 38, 41, 251, 252
Research Corporation of New England, 254
Revzan, KL, 249
Riley, RL, 55, 251
Ro, T, 37, 237
Robb, AW, 249
Robbins, RC, 251
Robinson, E, 251
Rodgers, SJ, 251
Roehlich, F, 251
Rogers, S, 53, 54, 251
Roseme, GD, 144, 235, 249, 251
Rosenfeld, AH, 231
Rosner, B, 256
Rubow, KL, 58, 244
Rudolph, H, 227
Russell, P, 35, 136, 251
Russo, A, 237
Sabersky, RH, 234, 251
Sackner, MA, 236
Saito, H, 259
Sauder, LR, 235
Savage, EP, 64, 252
Savel, H, 39, 252
Sawyer, RN, 252
Scheere, AR, 242
Scheffers, TM, 82, 257
Schiager, KJ, 233
Schmeltz, I, 237
Schmidt, H, 245
Schoenberg, JB, 229
Scholz, RC, 238
Schwartz, B, 243
Schwartz, HJ, 232
Seba, DB, 41, 252
Selikoff, IJ, 33, 120, 123, 125, 252
Selner, JC, 252
Serda, P, 252
Sereda, 73
Severs, RK, 24, 28, 87, 113, 252
Sexton, K, 244
Shair, FH, 234, 251, 252
Shakman, RA, 94, 252
Shalamberidze, OP, 24, 252, 253
Shaw, RA, 235
Shepard, E, 255
Shepard, RJ, 253
Shirtliffe, C, 145, 253
Shor, RE, 253
Shuler, PJ, 233
Shy, CM, 38, 253
Silberstein, S, 105, 108, 140, 141, 253
Silver, F, 111, 112, 116, 253
Silverman, F, 253
Sinema, DA, 251
Small and Associates, 3
Small, BJ, 254
Small, BM, 3, 95, 97, 123, 124, 145, 147, 165, 168, 253, 254
Smiley, RE, 250, 254
Smith, 88
Solomon, RL, 254
Solomon, WR, 244
Somers, E, 42, 44, 45, 254
Spedding, DJ, 122, 254

Speizer, FE, 20, 24, 235, 254, 256
Spengler, JD, 62, 228, 234, 235, 243, 244, 254
Sprague, DE, 47, 87, 231, 250, 254
Stanton, MF, 125, 255
Stark, JWC, 246, 247
Statute Revision Commission of Canada, 9, 19, 20, 255
Stead, AG, 237
Stedman, RL, 36, 255
Stephens, RJ, 234
Sterling, E, 10, 24, 63, 73, 133, 255, 256
Sterling, T, 10, 24, 63, 73, 133, 255
Stewart, RD, 12, 116, 255
Stokinger, HE, 255
Stone, R, 255
Strasser, AL, 40, 255
Suits, CW, 93, 250
Sunnyhill Low-Pollution Research Centre, 165
Sweigart, ML, 256
Swidersky, P, 241
Swift, DL, 227
Tabershaw, IR, 124, 256
Tager, IB, 40, 256
Tanaka, M, 256
Tanimura, A, 244
Thoburn, TW, 237
Thompson, CR, 256
Thurston, BE, 256
Tockman, MS, 238
Traynor, GW, 6, 9, 10, 18-20, 22-24, 27, 42, 44, 48, 104-106, 112, 115, 130, 135-137, 144, 153, 238, 239, 256
Trieff, NM, 256
Tucker, B, 255
Tucker, WF, 254
Turiel, I, 228, 229, 238, 256, 259
Turk, A, 231, 257
Turner, LG, 235
Turner, WA, 254
Ulsamer, AG, 42, 64, 67, 73, 74, 81, 228, 257
U.S. Air Force, 65
U.S. Department of Defense, 66, 67
U.S. Surgeon General, 39
Utidjian, HM, 256
Valbjorn, O, 121, 235, 243, 246, 257
Van Zant, GE, 257
Van der Lende, R, 257
Vasil'eva, TS, 257
Vasudev, P, 244
Veenstra, SJ, 234
Veneskoski, T, 247
Verberk, MM, 74, 82, 257
Villarreal, E, 255
Wade, WA, 20, 21, 103, 233, 257
Waldbott, GL, 6, 7, 18, 20, 22, 29, 30, 33, 34, 36, 53, 54, 68, 69, 70, 77, 83, 257
Walker, EA, 230
Walsh, PJ, 5, 234
Walter, P, 257
Wanner, A, 236
Ware, JH, 122, 243
Ware, WH, 257
Weber-tschopp, A, 257
Webster, X, 245
Weill, H, 258
Weiss, ST, 256
Weschler, CJ, 258
Wheeler, HW, 252
White, JR, 258
White, RP, 40, 236
Whitmore, FC, 258
Wigle, DT, 37, 39, 40, 41, 38, 39, 258
Wilberstein, 114
Willeke, K, 258
Williams, DC, 110, 144, 253
Williams, FW, 258
Wilson, RW, 229
Winchester, JW, 60, 247, 258
Winkelstein, W, 258
Wldbott, 50
Wolfson, JM, 235, 254
Wolochow, H, 234
Woods, JE, 235, 257
World Health Organization, 5, 19, 49, 52, 258
Wrench, C, 255
Wynder, EL, 113, 237, 258
Xintaras, C, 240
Yocom, JE, 10, 20, 21, 27, 62, 103, 233, 257, 259
Yoshida, 23, 31, 114
Yoshida, R, 259
Yoshizawa, S, 256
Young, GS, 9, 10, 18, 19, 24, 26, 27, 36, 60, 61, 63, 259

Young, JL, 235
Young, RA, 229, 239, 259
Zabransky, J, 247
Zamm, AV, 50, 96, 104, 116, 117, 123, 143, 145, 147, 148, 259
Zarubin, GP, 259
Zweideinger, RA, 111, 259

Index of Subjects

1,1,1 trichloroethane, 72, 75, 78, 80, 112, 115
1,1,2 trichlorethane, 81
1,2 dibromoethane, 112
1,2 dichloroethane, 81
1,2,4 trimethylbenzene, 78
2,4-D, 67
2,4DP pesticide, 47
2-methyl-1-propanol, 112
2-naphthylamine, in tobacco smoke, 39
3-xylene, 78
4-aminobiphenyl, in tobacco smoke, 39
abdominal pain, 66, 121
abrasive cleaners, 115
absorption of organics, 81
accelerators, 76
accident risk, 128
accidents, 97
accidents, in paint industry, 123
acetone, 36, 73, 74
acetone, from metabolism, 126
aches in the joints, 56
acid anhydrides, 51
acid-base balance, 49
acids, 36, 126
acrolein, 36, 38
acrolein, at low humidity, 131
acrylic acid esters, 76, 82
acrylic elastomer, 120
actinomycetes fungi, 60, 119
activated carbon, 149
activities of occupants, 126*, 128
activities, reduction of pollution, 154
acute exposure, 83
acute illness, 88
acyclic hydrocarbons, 72
adaptation, 30, 93, 158
adaptive mechanisms, 24
additive effects, 83, 98
adhesive cements, 96
adhesives, 42, 73, 76, 83, 110, 178
adhesives, PCBs in, 74
adipates, 76
adjusting product formulation, 156
adolescence, 88
adsorption on surfaces, 41, 69, 84, 142, 155
aerosols, 7, 41, 59, 73, 85
aerosols, consumer product, 58*, 60, 73
aerosols, emissions from, 115
aerosols, mixed with SO2, 27
agglomeration, 41
air barrier, 183
air change rates, 130
air conditioning, 52, 55, 60, 125
air ducts, with fibrous glass, 124
air exchange, natural, 130
air flow obstruction, 24
air mixing, 137
air mixing fans, and radon, 150
air movement, 136
air quality monitoring, 225
air quality standards, carbon monoxide, 9
air quality standards, nitrogen dioxide, 19
air quality standards, ozone, 29
air quality standards, particulates, 61
air quality standards, sulphur dioxide, 27
air quality standards, U.S., 13
airing of houses, 121
airplane cabins, ozone in, 31, 32
airtight construction, 183
airway defense mechanisms, 59
airway irritation, 121
alcohol as a risk factor, 90
alcohols, 36, 81, 115, 120
alcohols, in automobile interiors, 112
aldehydes, 7, 36, 51, 72, 74
aldehydes, aliphatic, 43
aldehydes, aromatic, 45
aldehydes, from motors, 117
aldehydes, halogenated, 45
aldehydes, health effects, 45
aldehydes, heterocyclic, 45
aldehydes, in automobile interiors, 112
aldehydes, unsaturated, 45
aldrin, 66
algae, 57, 60, 131
alicyclic hydrocarbons, 72
aliphatic aldehydes, 43
aliphatic amines, 77

aliphatic hydrocarbons, 72, 73, 81, 115, 116
alkaline cleaners, 115
alkaloids, 36
alkanes, 36, 74, 78, 80
alkenes, 80
alkilis, 126
alkyd resin, 121
alkyd resin, and mould growth, 54
alkyl halides, 111
alkyl phthalates, 76, 82
alkylated aromatic hydrocarbons, 72
alkylbenzenes, 74, 78
alkynes, 36
allergens, 6, 50, 84
allergens, defence against, 87
allergens in mould, 85
allergic alveolitis, 56, 119
allergic asthma, 83
allergic disease, from pollution, 88
allergic disease, increase of, 132
allergic history, 83
allergic reactions, from epoxy, 123
allergic reactions, from UFFI, 44
allergic response, 51, 54, 60, 62
allergies, number of people with, 97
allergy, 44, 57
alpha-energy concentration, 15
alpha particle emission, 16
alpha-pinene, 78
alternaria, 53
alternaria tenuis, 53
alternative materials, 155
alternative products, 127, 148
aluminum cleaners, 115
aluminum foil, 172, 179, 206, 213
aluminum foil vapour barrier, 123
aluminum soffiting, 179
aluminum, anodized, 178
aluminum, in aerosol, 115
alveolitis, allergic, 56, 119
amines, 74, 115
amino nitrogen compounds, 24
ammonia, 24, 68*, 85, 126, 96, 110
ammonia, from aerosols, 115
ammonia, in tobacco smoke, 36
ammonia, TLV, 68
ammonium hydroxide, 68, 115
ammonium sulphate, 68
amnesia, 13, 80
amoeba, 119, 55
amosite asbestos, 33
amplifiers, 57
anaesthesia, 49
anaesthetic, 75
anaesthetic effect, 59
anaesthetic property of aldehydes, 45
angina pectoris, 12, 39
angina pectoris, and smoking, 39
angina pectoris, and paint remover, 116
angioedema, 47
anhydrous ammonia, 68
aniline, 112
animal carcinogens, 80, 81
animal dander, 50, 61, 62
anodized aluminum, 178
anorexia, 66, 71
anthanthrene, 36
anthropod fragments, 60
anti-oxidants, 76, 111
anti-perspirants, 58
antibodies, specific for TDI, 83
antigenic compounds in dust, 50
antistatic agents, 76, 82
antistatic agents, in fabric, 110
anxiety, 70
appliance wires, 33
appliance housings, plastic, 131
appliance seals, rubber, 132
appliances, 6, 117*, 127
apprehension, 66
areflexia, 49
argon, 7
arno foil tape, 179, 206
aroclors (PCBs), 111
aromatic hydrocarbons, 72, 73, 81, 115, 120
aromatic hydrocarbons, in automobile interiors, 112
aromatic hydrocarbons, solvents, 115
aromatic polyamide paper, 117
arsenic, 110
arteriosclerosis, 12
arthralgia, 93
arthritis, 93
artists, 126
asbestos, 6, 33*, 84
asbestos paper, 33
asbestos, removal, 35

asbestos, standards, United States, 34
asbestosis, 34
ashphalt shingles, 178
aspergillus, 53, 54
asphyxia, 81
asphyxiant, 48
asthma, 45, 46, 66
asthma, allergic, 83
asthma, effect of pollution on, 87
asthma, from toluene di-isocyanate, 82
asthmatic disease, 91
ataxia, 66, 81
atmospheric pressure, 17
attapulgite, 61
aureobasidium (pullularia), 53
automatic dampering, 215
automobile exhaust, 9, 18, 20, 42, 60, 113, 114, 127
automobile exhaust and lead in humans, 114
automobile interiors, 111
avoidance of allergens, 51, 84, 88, 145
avoidance of chemical exposures, 112
bacteria, 6, 7, 50, 53, 55*, 85, 119
bacteria, defence against, 87
bacterial 'amplifiers', 57
bacterial infection, 56
bacteriostats, in fabrics, 110
baking of paint, 143
baking soda, 148, 151
balance, loss of, 123
balancing exhaust system, 192, 215
ballasts, PCBs in, 74, 79
bare floors, 212
barometric pressure, 14, 17
barrel chest, 34
basement, 184
basidiomycetes, 53
bathroom cleaners, 70, 115
bedding, 51
bedroom sanctuary, 196, 212, 213
bedrooms, 173
behavioural characteristics, 90
benzene, 63, 72, 75, 77, 78, 80, 112
benzene, from motors, 117
benzene, in paint remover, 116
benzene, in shellac, 121
benzo(a)fluorene, 36
benzo(a)pyrene, 28, 36, 37, 38, 109
benzo(a)pyrene, in automobile exhaust, 113
benzo(b/c)fluorene, 36
benzo(b/k/j)fluoranthrene, 36
benzo(e)pyrene, 36
benzo(ghi)perylene, 36
benzothiazole, 112
bhc(alpha, beta, gamma), 67
biological organisms, 52
biphenyl, 112
birth defects, 67
bismuth-214, 14
bisulphite, 28
bleach, household, 70
bleaches, in fabrics, 110
blender, 117
blindness, from methanol, 81
block, concrete, 183
blood pressure changes, 95
blood-brain barrier, 81
blowing agents, 77
blurred vision, 66
boiler, hot water, 190
borates, 124
boric acid, 124
borons, 124
botrytis cinera, 53
brake repair, asbestos, 33
breath, human, 74
breathing difficulty, 56
breathing problems, 124
breathlessness, 34
brick, 14, 142
bricks, clay, 177
bromine, 60
bronchial asthma, 23, 93
bronchial asthma, children, 114
bronchial congestion, 46
bronchial reactivity, due to ozone, 31
bronchial spasticity, 23
bronchitis, 24, 28, 66, 86, 93
bronchodilators, 58
bruising, 95
buffer, 182
bug killers, 70
building code, Canada, 153
building materials, 6, 72, 73, 74, 75, 78, 84, 93, 100
burning feeling, 111

burning of the eyes, 45
burns, 58
business space, Sunnyhill, 165
butane, 81
butyl acetate, 81
butyl ethers, 81
butylated hydroxytoluene (BHT), 73
c-n alkanes and alkenes, 75
c2-alkylbenzes, 126
cadmium, 36, 40, 104
canaries, 89
cancer, 67, 80, 84, 125
capacitors, PCBs in, 74
captan, 67
carbon dioxide, 6, 7, 36, 48*, 84, 136
carbon dioxide, and acid-base balance, 49
carbon dioxide, indoor levels, 48
carbon dioxide, outdoors, 48
carbon dioxide, standards, 48
carbon dioxide, TLV, 48
carbon disulphide, 112
carbon monoxide, 6, 9*, 11, 41, 59, 84, 86, 102, 103, 106, 108, 113, 114, 17, 126, 127
carbon monoxide, and methylene chloride, 116
carbon monoxide, concentrations, 9*
carbon monoxide, Canadian standards, 9*
carbon monoxide, effects on exercise, 11
carbon monoxide, effects on vigilance, 11
carbon monoxide, fatal exposure, 84
carbon monoxide, from plastic, 73
carbon monoxide, in tobacco smoke, 36
carbon monoxide, intoxication, 12
carbon monoxide, mortality due to, 11
carbon monoxide, poisoning, 4
carbon monoxide, risk to cardiac patients, 87
carbon monoxide, U.S. standards, 10
carbon tetrachloride, 112
carbon, 188
carbon, activated, 149
carbonless copy paper, PCBs in, 74
carboxyhemoglobin (COHb), 11, 12, 30, 116
carboxyhemoglobin, normal levels, 13
carboxylic acids, 110
carcinogens, suspected, 74
carcinogens, 80, 91, 112
carcinogenesis inquiry, 80
cardboard, 69
cardiac arrhythmia, 47, 59, 95
cardiac failure, 66
cardiac function, 81
cardiac patients, risk of CO, 87
cardiovascular disease, 12, 90, 158
cardiovascular disease, as risk group, 92
cardiovascular impairment, 85
cardiovascular system, 116
carpet, 42, 50, 60, 73, 74, 110, 219
carpet, analysis of outgassing, 111*
carpet, in sunlight, 131
carpet, shampoo, 115
carpet, wool, 26
carpet, wool, absorption, 142
catalyst accelerator, 77
catalyst deactivators, 110
catalysts, 110
cataracts, 69
caulking, 95
caulking, mono, 208
caulking, outgassing of, 220
caulking, polysulphide polymer rubber, 178
caulking, silicone, 178
cavity, closing at doorway, 204
cavity, vented, 185
cavity wall, 170, 183, 201, 212
cavity wall insulation, 213
cavity width, 202
cedar, 177
ceiling lighting, 193
ceiling panels, 191
ceiling tiles, 33
cellulose insulation, 95, 124, 128, 219
cellulose fabrics, 110
cellulosic materials, 53
cement board, asbestos, 33
cement, 61, 177
central exhaust, 192, 212
central nervous system, 48, 59, 80, 81, 111, 121, 123
central nervous system depression, 81
central nervous system disorders, 46

central vacuum, 51, 197, 212, 213
ceramic fibers, 60
ceramic materials, 144
ceramic tile, 180, 198, 213
cerebral dysfunction, 67
cerebral effects, 82
cerebral vascular disease, 12
cerebrovascular arteriosclerosis, 12
challenge testing, 45, 175
changes in building design, 147
changing the environment, 145
charcoal, activated, 149
charcoal granules, mould in, 54
chemical agents, defence against, 87
chemical plants, 68
chemical soup, 157
chemical susceptibility, 8, 46, 47, 67, 70, 71, 84, 85, 86, 93, 94, 96, 111, 117, 127, 136, 158, 161, 165, 174, 215
chemical susceptibility, and fiberglass, 125
chemical susceptibility, and fossil fuels, 108
chemical susceptibility, and furnishings, 112
chemical susceptibility, and ozone, 32
chemical susceptibility, and paint, 123
chemical susceptibility, and sealers, 151
chemical susceptibility, and wood smoke, 109
chemically susceptible persons, 223
chemicals, threshold values, 161
chemisorbant filter, 149
chest constriction, 45
chest infections, 86
chest pain, 12, 56, 95
chest tightness, 56
children, effects of smoke, 39
children, lead levels, 114
children, pollutant effects on, 87, 114
chimney liners, 102
chimneys, faulty, 4, 13, 102*, 127, 223
chimneys, industrial, 9
chimneys, neighbouring, 113, 127
chimneys, public utility, 9
chloracne, 82
chloramine gas, 71
chlordane, 64, 67
chlorinated aliphatic hydrocarbons, 66
chlorinated hydrocarbons, 72, 77, 115, 120
chlorinated phenols, 120
chlorine, 47, 70*, 85
chlorine, in aerosol, 115
chlorine, TLV, 70
chloro benzenes, 75, 80
chloroform, 112
chlorophyll, 52
chlorox, 96
choice of environment, by individual, 217
choking, 27
chrome cleaners, 115
chromium compounds (pigment), 120
chromosomal aberrations, 31
chromosomal effects, 82
chronic exposure, 83
chrysene, benz(a)anthracene, 36
chrysotile asbestos, 33
cigarette smoke, sidestream, 6
cigarette smoke, 36*
cigarettes, 37
cigars, 37
cilia, 22
circadian rhythms, 88, 91
city dwellers, lead levels, 114
cladosporium (hormodendrum), 53
clays, 61
clean air, outdoors, 6, 7
cleaners, household, , 58, 68, 73, 75, 115*, 127, 157, 219, 221
cleaners, nontoxic, 148
cleaning, 51
cleaning, substitute products, 155
clinical facilities, 225
clinical wing, 173
cloth, 60
clothing, 50
clutter, reduction of, 194
co-ordination, effect of CO on, 12
coal smoke, 70, 96
coal stove or furnace, 18, 109
coal, 26, 96

coating pollutant surfaces, 151
cocktail lounge, smoke in, 37
coke ovens, 68
colds, 46
colourants, 76, 82
columns, steel, 184
coma, 13, 49, 66
combustion, 6, 9, 18, 42, 60, 68, 73, 84, 96, 131, 157, 160
combustion, incomplete, 9
combustion, products, 6
combustion, slow, 73
comminuted talcs, 60
complement levels, 45
composition boards, 157
concentration, difficulty with, 93
conclusions, 157
concrete block, 177, 183
concrete floor, 212
concrete, 14, 73, 74, 142
concrete, and irritation, 121
concrete, imperfections, 209
concrete, poured, 184
condensates, 54
condensation and corrosive gases, 132
condensation nuclei, 7
condensation of volatiles, 60
condensation, within walls, 131
condensing heat pumps, 146
confusion, 49, 56, 66, 81
consciousness, loss of, 22
construction, low-pollution, 163
construction supervision, 201, 207
construction techniques, 201
consumer education, 126, 221
consumer product aerosols, 6, 58*, 70, 85
control of pollutants, 145
control system, 136, 154, 156
controls, automatic, 215
convergence, 31
convulsions, 66
cooking oil, 58
cooking, 60, 73, 75, 103, 126, 153, 195
cooling towers, 57
coordination problems, 80
copper cleaners, 115
coronary artery disease, 28
coronary vascular disease, 13
corrosion of mortar, 102
cortical function, depression, 31
cortical reflex, formaldehyde, 45
cosmetics, 76
cost implications, 222
cost, of energy, 222
cost, of filtration, 222
cost, of renovation, 222
cost, of sealing vapour barrier, 222
costs, of indoor air pollution, 226
costs, medical, 100
costs, social and economic, 100
cotton, 69, 213
cotton, in dust, 50
cough, 40, 46, 56, 66, 70, 38, 44, 45, 46, 94, 95, 124
coughing blood, 124
coughing, and infection, 55
craft materials, 73
creosol, in automobile interiors, 112
crocidolite asbestos, 33
croup, 86
crowding, and pollution, 133
cumulative action of TDI, 83
cupboards, 172, 212, 213
cupboards, vented, 194
curing agents, 76
current practice, 217
cutbacks in research, 98
cyanosis, 34, 95
cycloaliphatic hydrocarbons, 72
cyclohexane, 72, 73
cyclopentane, 72
cystic fibrosis, 91
dampness, 52, 53, 85
danders, 6, 50
dark adaptation, 23
DDE, 67
DDT, 66, 67
DDVP (pesticide), 64
decane, 78
decay, organic, 7
decaying animal matter, 7
decaying plant matter, 7
decomposed material, 50
decorative materials, 127
decreased ventilation, 57
defence mechanism, 87
degeneration of peripheral nerves, 81

degreasing agents, 73, 75
delustrants, 110
demyelination, 81
deodorants, 74, 58, 70, 96, 115
deodorizers, 73, 115, 157
deodorizers, stick, 115
deodorizers, spray, 115
depression, 80, 124
depressive psychoses, 13
dermatitis, 83
design changes, 155
design effectiveness, 212, 215
design features, 181
design principles, 168
detail, 173
detergents, 96, 115
developmental influences, 90
di-(2-ethylhexyl) phthalate (DEHP), 82
di-(2-ethylhexyl) adipate, 82
diarrhea, 46, 94
diazinon, 64, 66
dibenz(a,h)anthracene,
 ideno-(2,3-ed)pyrene, 36
dibenz(a,j)anthracene, 36
dibenzoates, 76
dibromodichloroethanol, in carpet, 111
dichlorobenzene, 96, 112
dichlorobenzene isomer, 112
dichloroisocyanuric acid, 70
dichloromethane, 116
dichlorvos, 66
dieldrin, 66
diesel fumes, 210
diethyltetramine, 76
differential susceptibility, 90
digestive symptoms, from paint, 123
digestive tract, 62
dilution of pollutants, 135, 155
dimethyldichlorohydantoin, 70
dimethylether, 81, 112
dimethylformamide (DMF), 73
dimethylnaphthalenes, 72, 112
dimethylol dihyroxyethyleneurea,
 in fabrics 110
dimethylphenol isomers, 112
dimness of vision, 49
dinitrophenols, 67
diones, 51
dioxane (1,2,4), 81
dioxane, 81
diphenoxybenzene, 112
diphenyl guanadine, 76
diphenyl mercury dodecenyl
 succinate, 122
dishwashing, 131
disinfectants, 96
disorientation, 81
displacement of oxygen, 81
distilling research, 224
diversity of population, 83
dizziness, 13, 44, 46, 47, 49, 64,
 66, 70, 82, 123, 124
DNA damage, 82
do-it-yourself painting, 123
domestic animals, 55
draft, chimney, 108
drain cleaner, 71
dressing room, 196
droplet nuclei, 41, 55
drowsiness, 46, 81
drug action, effects of ozone on, 31
drugs, as a risk factor, 90, 91
dry cleaning, 74, 75
dry upper airways, 121
drywall, 178
drywall taping compounds, 34
durable press, 110
dursban (pesticide), 64
dust, 6, 7, 60
dust allergy, 51
dust, house, 50*, 84
dust mites, 50, 130, 132
dust, organic, and bacteria, 119
dust, resuspension, 60
dyes, 42, 50, 95
dyes, in fabrics, 110
ECG effects, 12
economic disruption, 100
edema, 93
education, 165, 221
EEG activity, abnormal, 31
EEG effects, formaldehyde, 45
effectiveness of design, 212, 215
elastomers, 110
elderly people, 40, 88, 158
electric boiler, 190
electric heat, 172
electric motor, 117
electric odour, 29
electric stove, 20, 22, 144

electric wire coatings, 95
electrical appliances, 117*, 127
electrical cable BX, 180
electrical capacitors, PCBs in, 74
electrical equipment, high-voltage, 31
electrical transformers, PCBs in, 74
electroencephalograph (see EEG)
electronic appliances, 117
electrostatic filter, 6, 29, 30, 84, 117, 149
electrostatic filter, for radon, 150
emphysema, 13, 22, 34
emulsifying agents, 120
emusion paint, 121
enamelled steel, 178
endosulfan I, 67
endosulfan sulphate, 67
endrin, 67
energy conservation, 1, 4, 38, 39, 129, 132, 136, 160, 220
energy cost, 222
energy efficient houses, 43, 130, 138
energy loss, from ventilation, 136
energy, cutback in, 93
environmental unit, 93
eosinophil count, 96
epichlorohydrin, 76, 82
epicoccum, 53
epithelial damage, 31
epoxides, 51
epoxies, 123, 126
epoxy esters, 76
epoxy paints, 123
epoxy resins, 76, 82
epoxy sealant, for radon, 151
equilibrium factor, 15
equilibrium, loss of, 66
esters, 36, 73, 76, 81, 120
ethanol, 73, 74, 78
ethers, 36, 76, 81
ethers, in automobile interiors, 112
ethyl acetate, 81
ethyl alcohol, 58, 121
ethyl benzene, 75, 78, 80
ethyl butyrate, 81
ethyl ethers, 81
ethylene glycol, 81, 115, 120
evaporation, 110, 131
evaporative condenser, 57
exchange rates and gas concentrations, 137
excitation, 81
exhaust, central, 170, 186, 192
exhilaration, 123
exposure, duration of, 8
exposure, in testing, 175
exposures, individual, 99
exterior furnace, 146
exteriorizing pollutants, 169
extermination, 64
external storage, 222
eye damage, 68
eye discharges, 82
eye injury, 80
eye irritation, 38, 40, 44, 46, 46, 59, 62, 67, 68, 69, 70, 80-82, 93, 121
eyes watering, 174
fabric filters, 149
fabrics, 26, 50, 73, 110*, 111, 142, 157
fabrics, asbestos in, 33
fabrics, formaldehyde in, 42
facial angioedema, 47
factories as pollutant sources, 113
fan capacity, 222
fans, 192
fatigue, 46, 47, 80, 81, 94
fatty acids, 111
faucet aerators, 57
feathers, 50, 61
feedback control systems, 154, 156, 225
ferbam (fungicide), 67
fetal development, 88
fever, 54, 56, 67, 68, 94, 95
fiberglass, 42, 219
fiberglass insulation, 60, 124, 128, 177, 213
fiberglass, rigid, 177
fibrositis, 93
fibrous glass, 124, 125
fillers, 76, 82
fillers, in paint, 120
filter media, 188
filtering intake air, 187
filters, carbon, 149
filters, chemisorbant, 149

filters, fabric, 149
filters, fiberglass, 149
filters, high-efficiency, 149
filters, oil-impregnated, 96
filters, on cupboards, 194
filters, Sunnyhill, 172
filtration, 51, 135, 140, 149, 155, 169, 186, 221
filtration, of radon, 149
filtration of intake air, 212
fire retardant, 95, 110, 111, 124
fire retardant, asbestos, 33
fire retardants, hydrolysis of, 111
fire retardants, PCBs, 111
fireplaces, 9, 60, 109
fireproofing agents, PCBs in, 74
flexibility, 173
floor drains, 14
floor polishes, 116
floor/wall joints, 14
floor wash, 95
flooring, soft, 95
floors, 184
floors, bare, 198
floors, ceramic, 198
floors, hardwood, 198
flue gases, 48
fluoranthene, 36
fluorescent light ballasts, PCBs in, 74, 79
fluorescent fixtures, 193
fluoride, 36
fluorocarbons, from aerosols, 115
flushing of pollutants, 168, 169
flushing, facial, 95
fly ash, 60
foam furnishings, 219
foam furniture, in sunlight, 131
foam, latex, 111
foam products, 77
foil, aluminum, 172, 179, 206
foil-covered boards, 151
foil tape, 172, 179, 206
food allergies, 126
food leftovers, 50
food odours, 126
food particles, 50
foot products, 58
forced expiratory volume (FEV), 24
forced vital capacity (FVC), 24
forgetfulness, 93
formaldehyde, 6, 36, 42*, 47, 51, 73, 75, 80, 84, 86, 95, 103, 106, 108, 110, 115, 124, 130
formaldehyde, and sensible-heat exchanger, 139
formaldehyde, at high humidity, 131
formaldehyde, from kerosene heaters, 44
formaldehyde, from motors, 117
formaldehyde, in deodorizers, 115
formaldehyde, in mildew proofing, 115
formaldehyde, in tobacco smoke, 36
formaldehyde, standards, Canadian, 42
formaldehyde, standards, other countries, 43
formaldehyde, TLV in workplace, 42
forum for communication, 224
fossil fuels, 9, 26, 146
fossil fuel furnaces, 84, 108, 127
fossil fuel heaters, 84
foundation cracks, 14
framing, 184
framing, wall, 185
freon, 58
fresh air, 136
fuel consumption, 1
fumes, diesel, 210
fumigants, 42, 111
functional capability, 12
funding, 168
fungal disease, 88
fungi, 6, 7, 50, 52*, 55, 60, 85, 119, 131
fungi, defence against, 87
fungi, in charcoal, 149
fungi, in UFFI, 44
fungicides, 67
fungistats, in fabrics, 110
fungicides in paint, 54
fungicides, mercury, 121
fungus, control of, 51
furnace, faulty, 84, 86, 160, 219
furnaces, fossil fuel, 84, 108
furnaces, adjustment, 155
furnishings, 42, 50, 73, 84, 110*, 127, 157, 221
furnishings, bare, 212
furnishings, foam, 219
furnishings, washable, 199

furniture, 43
furniture polish, 116
fusarium, 53
garages, attached, 9, 10, 13, 18, 113, 219
gas boiler, 146
gas chromatography, 72, 73
gas driers, 96
gas fired heat pumps, 146
gas furnaces, 9, 60, 95, 127, 146, 219
gas/liquid chromotography, 111
gas ovens, 9
gas refrigerators, 96
gas space heaters, 9, 18, 42, 146
gas stoves, 9, 10, 18, 20, 21, 24, 42, 60, 84, 86, 87, 96, 103*, 127, 146, 219
gas stoves, pilot, 10
gas stoves, self-clean cycle, 10
gas stoves, emissions, 103*
gas stoves, ventilation, 153
gas supply lines, 95
gas water heaters, 9, 18, 21, 42, 95, 96
gaskets, 178
gasoline, 75, 113
gasoline, in varnish, 121
gasoline, leaded, 113
gasoline, spillage, 208
gasoline, unleaded, 75
gassing out, 1, 169
gassing out period, 143, 155
gassing out, accelerating, 152
gastrointestinal symptoms, 93, 124
general chemical susceptibility, 88, 93
general population, 86
genetic factors, 90
germicides, 42
germination of mould spores, 52
glass fibers, 62
glass, in furnishings, 199
glass walls, 213
glazes, 126
glazing, 178
gloves, asbestos, 33
glues, 157
glycols, 120
grain dust, 61
granulomas, 88
grease, spillage onsite, 208
green plants, 7
groundwater, 14
hair dryers, with asbestos, 33
hair products, 58
hair spray, 58, 59, 70
hairs, 50
halocarbons, 73
halogenated ethanols, 111
halogenated compounds, 112
halogenated hydrocarbons, 81
handicapped population, 223
hangover effects, 93
haptens, 51
hardwood, 69, 179
hardwood flooring, 198
hardwood furnishings, 199
hayfever, and tobacco smoke, 39
hazard, health, 123
hazard, safety, 123
headache, 13, 38, 39, 44, 46, 49, 59, 64, 66, 70, 80, 81, 82, 93, 95, 121, 174
headache, due to CO, 12
headspace vapour, 73
health effects, 157
health effects, acceptable levels, 162
health effects, long term, 99
health promotion, 162
health research, 225
healthy people, risks to, 88
hearing, effect of CO on, 12
hearing loss, 13
heart disease, 91
heart injury, 80
heat exchangers, 136, 155, 160, 187, 221
heat exchangers, air-to-air, 135
heat exchangers, cost, 222
heat exchangers, defrost cycle, 137
heat exchangers, furnace, cracks in, 108
heat exchangers, membranes, 137
heat exchangers, sensible-heat type, 139
heat exchangers, with heat pump, 186
heat loss, 202
heat pump, 187, 190, 213
heat pump, gas-fired, 146
heat storage media, 14

heat, hot water system, 190
heat, low-temperature, 172
heat, radiant, 191
heat, reclamation, 190
heater floor pads, asbestos, 35
heaters, fossil fuel, 84
heaters, unvented, 106
heating elements, spills on, 9
heating systems, 55
heating systems, odours, 96
heavy metals, 124
heavy metals, in fabric, 110
hemoglobin, 11
heptachlor, 67, 94
heptachlor epoxide, 67
herbicides, 67
heterocyclic compounds, 36
hexachlorabenzene, 67
hexachloroethane, 81
high-efficiency filters, 149
high-risk groups, 40, 90, 91
high-risk population, size, 91, 99
high-risk groups, and
 standards, 92
histamine release, 23
hives, 83
hoarseness, 45, 95, 124
hobbies, 6, 73, 126, 128
hollowell, 152
home cleanup, 112
hormodendrum (cladosporium), 53
hot water boiler, 190
hot water heat, 190, 212, 213
hot water heater, 57
hot water systems, 57
hot water tanks, legionella in, 56
house dust, 50*, 84
house rules, 172, 200, 212
household products, 60, 94, 116
household chemicals, 115*, 127, 219
housing, for chemically
 susceptible, 165
housing, low-pollution, 96, 158
housing market, 158
housing standards, 159
housing, that promotes health, 162
human activity, 55
human factor control, 154, 156
humdifier, 52, 54, 55, 56, 57,
 60, 85, 128
humidifier fever, 54, 56
humidifier, pan-type, 57
humidifier, spray-type, 57, 119*
humidifier fever, 92
humidity, increased, 23, 50, 52,
 130, 131*
hydrocarbons, 7, 40, 72*, 79, 91
hydrocarbons, ambient air quality
 standards, 77
hydrocarbons, outdoors, 113
hydrocarbons, total, 79
hydrochloric acid, 70
hydrogen chloride, 110
hydrogen cyanide, 24, 36, 117
hydrogen cyanide, in tobacco
 smoke, 36
hydrogen peroxide, 110
hydrolysis products, 110
hydroquinine, monobenzylether of, 76
hydroscopic substances, 7
hyperirritability, 66
hyperpigmentation, 82
hypersecretion, 23
hypersensitivity, 51, 93
hypersensitivity, to formaldehyde, 44
hypersensitivity, to tobacco, 39
hypersusceptible (see chemical
 susceptibility)
hypotension, 49
IgE antibody, 51
IgG levels, 96
immune suppression, 96
immune system, deficiency with
 age, 91
immune system, immature, 91
immunoglobulin A deficiency, 91
immunological reactions, 51
immunologic hypersensitivity, 91
immuno-sensitization, 62
immuno-suppressive effects, 87
incineration, 42, 68
incoordination, 80
increasing pulse, 95
individual choice, 217
indoor/outdoor ratio, 63
indoor pollution, factors
 aggravating, 129
indoor pollution, social costs, 160
indoors, time spent, 98
industrial exposures, 60

industrial hygiene, 8
infants, 90, 158
infection, 57
infectious agents, 55*
infectious disease, defence against, 88
infiltration, 130, 183
influenza, 56
information base, 3, 99, 224
inlets, for air, 186
inorganic fibers, 60
insect spray, vinyl chloride, 58
insecticides, 64
insecticide poisoning, 66
insecticide sprays, 96
insects, 7, 60
insulated shutters, 189, 204
insulation, 42, 74, 124*, 128
insulation, cavity-wall, 177, 201
insulation, cellulose, 219
insulation, fiberglass batts, 177
insulation, interior, attachment, 204
insulation, odour, 204
insulation, outgassing of, 220
insulation, pipe, 33
insulation, styrofoam blue, 177
insulation, Sunnyhill, 170
intellectual impairment, 95
interior decorating, 6
interpretation of literature, 157
intoxication, 22, 81
intrusion of outdoor pollutants, 6, 113*
ion generator, 32, 41
iron deficiency, 91
iron, 60, 104
irritability, 66
irritant effects, 86
irritation, airway, 45, 74, 78, 80, 121
irritation, due to SO2, 27
irritation, due to tobacco smoke, 38
irritation, from ozone, 30
isobutane, 81
isobutyl alcohol, 112
isocyanates, 83, 91, 120
isolation of individuals, 170
isopropylbenzene, 112
itchiness, 46, 95
jerking movements, 66
jet lag, 88, 91
joint pains, 124
joists, open-web steel, 184
kerosene heaters, 9, 18, 22, 42, 44, 48, 60, 84, 86, 106*, 127, 146, 219, 223
kerosene heater, convective type, 10
kerosene heaters, emission rates, 106*
kerosene, in household cleaners, 115
ketones, 7, 36, 72, 73, 76, 110, 120
ketones, in automobile interiors, 112
kidney damage, 56, 80
kidney damage, from PCP, 76
kilns, 126
kitchen counter, 180
kitty litter, 61
labour cost, for vapour barrier, 222
lack of initiative, 93
lacquer remover, 76
lacquer thinners, 116
lacquers, 76
lacrimation, 38
laminates, 180
lanolin, 58
laryngeal edema, 47
latex foam pillows, 111
latex paint, 42, 120, 143
latex sealer, 35
lath, metal, 199
laundry products, 85
laundry starches, 115
layout, 195
lead compounds, (pigment), 120
lead, 36, 40, 60, 62, 104, 113, 128
lead, in house dust, 114
lead, in paints, 120
lead, in varnish, 121
lead-214, 14
leather products, 42
leg pain, 12
legal liability, 99
legionella, 56, 119
legionellosis, 56
lethargy, 81, 124
leukemia, 81
liability, 99
life style, 90
light flux, 110
light-headedness, 123
lighting, 193, 212

lighting, ultraviolet, 133
lime, 179
lindane, 66
linear hypothesis, lung cancer, 16
liners, chimney, 102
lipid solubility of organics, 81
lists of materials, 224
lithopone, 120
liver damage, 46, 56, 59, 80
liver damage, from PCP, 76
load, total stress, 86
local air supply, 187
location, of home, 212
location, Sunnyhill, 182
log homes, 76
Los Angeles County, 11
loss of balance, 123
loss of equilibrium, 66
loss of pulse, 95
loss of voice, 70
low-emission materials, 144, 155
low-emission materials, Sunnyhill, 172
low-pollution design, 163, 223
low-pollution housing, 96, 223
low-temperature heat, 172
lubricants, 58
lubricants, in fabric, 110
lubricants, PCBs in, 74
lubricating oil, 76
lung absorption, 81
lung changes, due to ozone, 30
lung changes, from NO2, 22
lung damage, from PCP, 76
lung damage, 80
lung disease, 85
lung function, 24, 56, 83
lung inflammation, 59
lymphocyte transformation, 39
lymphocytosis, 68
m-xylene, from motors, 117
maintenance, 6
maintenance products, 72
maintenance of furnace, 150
maintenance practices, 148, 155, 221
makeup, 126
maladaptation, 93, 94
malaise, 56, 95
malathion, 64
maleic anhydride, 112
maneb (fungicide), 67
manic psychoses, 13
manufacturing processes, 99, 152
maple hardwood, 213
marble, synthetic, 180
margin of safety, 217
marsh gases, 7
mass spectrometry, 72, 73, 111
materials, choice of, 154
materials, low-emission, 160
mattress dust, 50
media, filtration, 188
medical unknowns, 98, 99, 161
mental confusion, 56
mental performance, effect of CO on, 13
mercaptobenzothiazole, 76
mercury, 128
mercury, absorption on surfaces, 122
mercury, accumulation, 122
mercury, adsorption, 142
mercury droplets, 122
mercury, in paints, 120
mercury outgassing from paint, 122
mercury poisoning, 121
mercury sensitivity, 121
mercury thermometer, 122
mercury vapour, in homes, 121*
mercury, TLV, 122
mesothelioma, from asbestos, 34
mesothelioma, with fibrous glass, 125
metabolic activity, 68
metabolic gases, 126
metabolic products, 6, 74
metal furnishings, 199
metal lath, 199,
metal salts, in fabrics, 110
metallic materials, 144
metallic taste, 22
metals, 60
metals, in fabrics, 110
metals, in tobacco smoke, 36
meteoric dusts, 7
methoglobinemia, 22
methoxybenzaldehyde, 112
methoxychlor, 66
methyl alcohol, 121
methyl bromide, 111
methyl chloroform, 81

methyl ethyl ketone (MEK), 73, 77, 112
methyl ethers, 81
methyl-napthalenes, 72
methylcyclohexane, 77
methylene chloride, 81
methylene chloride, in aerosols, 59
methylene chloride, in mildew proofing, 115
methylene chloride, in paint remover, 116
microbes, 126
microorganisms, 55, 128
microsphaereopsis, 53
microwave ovens, 118
migraine, 39
mildew, 52*
mildew proofing, 115
mildewcides, mercury, 121
mineral fibers, 6, 60
mineral spirits, 75, 96, 116, 120
mineral wools, 60, 62
mineworkers, 15
mites, dust, 50
mobile homes, 4, 47
modifying combustion processes, 146, 155
moisture, 52, 53, 57
moisture, for gassing out, 143
monday sickness, 56
monilia, 54
monitoring, 214
monitoring devices, 225
monkeys, effects of CO on, 12
mono caulking, 208
monobenzylether of hydroquinine, 76
monomers, 76, 82, 110
mononucleosis, 89
monosulphide, 76
morbidity, 5
morbidity, from air pollution, 87
mortality, due to CO, 13
mortality, from benzene, 81
mortality, from CO2, 49
mortality, from methyl bromide, 111
mortality, from pesticides, 66
mortality, in newborn animals, 30
mortality, premature, 5
mortar cement, 177
mortar, dripping in cavity, 202
mothballs, 64
motor control, loss of, 46
motor odours, 197
motors, oil odour from, 96
mould, 7, 13, 52*, 85, 131, 140, 187
mould, allergenicity of, 54
mould allergy, 54
mould, concentrations, 52
mould, in rock storage, 221
mould spores, 60, 119
mouth products, 58
mucor, 53
mucous membranes, 62
mucous membrane irritation, 67, 68, 78, 81, 82
mucous velocity, 59
muffler repair, asbestos, 33
municipal water supply, 14,70,71,85,95
muscle pain, 121
muscle tremors, 66
muscle weakness, 81
muscular disturbances, 67
myalgia, 68, 93
mycelial fragments, 54
myocardial infarction, 12, 13
myocardial depression, 81
myocardium, 12, 30
n-butane, 112
n-heptane, 77
n-hexane, 77, 81
n-octane, 77
nano-curie, 15
naphtha, 115
naphthalene, 96, 112, 115
narcosis, 81
narcotic effects, 80
nasal burning, 95
nasal cancer, 44
nasal congestion, 46
nasal stuffiness, 95
nasal symptoms, 83
natural fibers, 51
natural gas, 14, 96
natural pollutants, 6, 7
nausea, 13, 38, 45, 59, 64, 66, 94, 95, 123
negative ion generator (see ion generator)
neoplastic effects, 112
neoprene glazing, 178

neuritis, 13, 93
neurological changes, 82
neurological changes, due to CO, 13
neurological effects, 82
neurological symptoms, 66
neurological symptoms, from NO, 22
neurotoxic disorders, from paint, 123, 128
new housing, hazards of, 159
new materials, 133, 159
nickel, 40
nicotine, 36, 37
night vision, 31
nitrates, 22, 24, 60
nitric acid, 22, 24
nitric oxide, 6, 18*, 103, 106, 108, 113
nitrogen, 7, 18, 36
nitrogen compounds, in automobile interiors, 112
nitrogen dioxide, 6, 18*, 84, 86, 103, 106, 108, 113, 114, 127
nitrogen dioxide, and Vitamin A, 32
nitrogen dioxide, outdoor levels, 20
nitrogen dioxide, standards, 19
nitrogen oxides, 18*, 36, 84
nitrogen oxides, from motors, 117
nitrogenous resins, 110
nitrous acid, 22
nitrous oxide, 22
nitrous oxide, in aerosols, 59
no-pest strips, 64
non-fibrous organic particulates, 60
non-smokers, 38, 40
non-specific irritants, 51
nonane, 78
nonsmokers, 11, 12, 59, 84, 153
nose bleeds, 46
numbness, 66
nutritional deficits, 90, 158
nutritional differences, 94
nylon, 69, 110
oasis, 196
objectives, 2
obstructive lung disease, 62
occupancy level, 133
occupational medicine, 90, 93
odour modifiers, 110
odours, 7, 83, 126
office trailers, 43
oil furnaces, 60, 146
oil paints, 54
oil smoke, 60
oil supply lines, 95
olefins, 45
olfactory recognition thresholds, 22
oligomers, 110
open concept, 195
open system theory, 168
opening mail, 126
o-phenyl phenols, 120
ore crushing and grinding, 60
organic chemicals, 7
organic dust, 62, 119
organic fibers, 60
organic fungicides, 122
organic halides, 111
organic matter, 52
organic materials, 144
organic mercury compounds, 122
organic vapours, 72*, 78, 81, 85, 115, 126, 127
organic vapours, standards, 77
organochlorine compounds, 64
organophosphates, 64
organophosphate insecticides, 66
organotin compounds, 76, 82
outdoor air pollutants, 4
outdoor pollutants, intrusion of, 113*
outdoor pollutants, variations, 140
outdoor pollution, 127, 136
outdoor pollution, protection from, 141
outgassing, 6, 93, 110, 117, 131
outgassing from sealants, 123
outgassing, under heat, 131
oven cleaner, 71
overview studies, 4
oxidation-reduction reactions, 73
oxidative stress, 110
oxygen, 7, 18, 26, 29
oxygen, displacement of, 81
oxygen level, 104
oxygen, transport in the body, 11
o-xylene, from motors, 117
ozone, 29*, 84, 113, 114, 117, 150
ozone, standards, Canadian, 29
ozone, standards, United States, 30

ozone, systemic effects, 31
ozone, uptake by aluminum, 142
pain of the lower extremities, 13
paint, 54, 73, 74, 75, 95, 120*, 123, 128
paint, and chemical susceptibility, 151
paint, gas-out period, 143
paint, indoor, 179
paint, ingredients, 120*
paint, latex, 42
paint, leaded, 113
paint, leaded, particles from, 62
paint, mildew-resistant, 121
paint, mould in, 53
paint, odours, 96
paint, PCBs in, 74
paint, remover, 59, 116*
paint, resin-based, 54
paint, rust, 178
paint, spray, 83
painters, health effects in, 120
painting in summer, 148
pallor, 93
palmitic oxide, 111
palpitation, 93
paper, formaldehyde in, 42
paper mache, 33
papillary constriction, 66
paradichlorobenzene, 115
paraformaldehyde, 115
parathion, 66
parging, 177, 183
parking garages, 9
particleboard, 4, 42, 44, 47, 75, 88, 131, 157, 177, 219, 221, 223
particlebard, laminated, 151
particleboard, low emission, 144, 152
particleboard, removal, 145
particulate matter, 41
particulates, 130
particulates, outdoors, 113
passive smoking, 38, 40, 159
passive solar heat, 212
PCBs (polychlorinated biphenyls), 74, 75, 77, 78, 79, 80
PCBs, in indoor air, 79
PCBs, in wallboard, 111
peak outdoor pollution, 155
peak pollutant episodes, 140
penicillium, 53
pentachlorophenol, 76, 82, 115
perceptions on indoor pollution, 5
performance, subcontractor, 210
perfume, 58, 74, 76, 95, 115, 116
perfumes, policy, 172, 200
peripheral blanching, 95
peripheral nerves, degeneration, 81
peripheral vascular disease, 13
permanent press fabrics, 95, 110
personal hygiene products, 58
personality disorders, 67
perspiration, excessive, 93
perylene, 36
pest control, 148
pesticides, 6, 58, 64*, 73, 75, 80, 85, 95, 157, 219
pesticides, in blood, 67
pesticides, nutritional effects, 94
pesticides, PCBs in, 74
pesticides, use, 64
pet insecticides, 64
petechiae, 95
petroleum alcohol, 47, 95
petroleum distillates, 66
petroleum distillates, in furniture polish, 116
petroleum naphtha, in floor polish, 116
petroleum products, 208
petroleum refineries, 26, 68
petroleum solvents, 72, 115
pets, 60, 128
pharyngeal dryness, 23
phenolic resin, 121
phenols, 36, 47, 95, 112
phenols, in tobacco, 36
phenyl mercuric proprionate, 121
phenyl mercury acetate, 121
phenyl mercury oleate, in paint, 121
phenyl mercury succinate, 121
phenylbeta napthylamine, 76
phlebitis, 95
phosphates, 76
photochemical haze, 7
photochemical oxidants, 78
photochemical smog, 133
photocopiers, ozone from, 29, 72
photographic supplies, 42
photophobia, 71

phthalates, 76
physician, 175
physics of indoor air pollution, 168
pico-curie, 15
pigments, 6, 54, 120, 126
pillows, latex foam, 111
pilot light, 103, 105
pine, 177
pine oil, 115
pine-scented floor wash, 95
pipe, tobacco, 37
pipes, copper, 180
pipes, drain, plastic, 180
piping, vacuum, 197
placemats, asbestos, 33
plants, 60
plaster, 61, 178, 185
plaster, mould in, 53
plaster, of paris, 179, 213
plaster, textured, 199
plaster, unpainted, 199, 212
plasterboard, 52
plastic appliance housings, 131
plastic drain pipes, 180
plastic furniture coverings, 111
plastic laminate, 151
plastic solvents, 75
plastic tape on furnace ducts, 132
plastic upholstery, 96
plastic vapour barrier, 95, 123
plasticizers, 75, 76, 82
plastics, 42, 73, 110, 126, 157
plastics, PCBs in, 74
plywood, 42, 44, 75, 177
pneumonia, 28
pollens, 7, 50, 62, 113, 140, 187
pollutant sources, 101
pollutant sources, minimizing, 139
pollutants, daily cycles, 114
pollutants, detection, 136
pollutants, reducing sources, 160
pollutants, to monitor, 214
pollutants, total mix, 112
pollution episode, 136
pollution, factors reducing, 134
pollution, from new materials, 133
pollution monitors, 192
pollution on construction site, 210
polonium, 149
polonium-210, in tobacco smoke, 36
polonium-214, 14
polonium-218, 14
polychlorinated biphenyls (see PCBs)
polyesters, 76, 110
polyethylene, 179, 213
polyethylene tape, 205
polymers, 76, 82
polynuclear aromatic hydrocarbons (PAH), 36, 38, 117
polyol, 77
polystyrene insulation, 151
polysulphide polymer rubber caulking, 178, 213
polyurethane, 76, 143
polyurethane, burning, 83
polyurethane foams, 77
polyurethane resin, 121
polyuria, 95
polyvinyl acetate monomer, 120
polyvinyl chloride (PVC), 110, 111
polyvinyl chloride pipes, 73
population affected, 225
population, chemically susceptible, 218
population, general, 86
population, number in high-risk groups, 91, 99, 157, 158
population, number susceptible, 96, 97
porcelain, 180
portable heaters, plastic components, 131
portland cement, 177, 213
portland/lime cement parging, 177
potters, 126
power generation plants, 113
precursor, to radon, 14
pregnancy, 13, 90, 126
prenarcotic symptoms, 123
preservatives, wood, 76, 95
pressure in the head, 45
printing inks, PCBs in, 74
printing pigments, in fabrics, 110
printing products, 42
problem materials, 218
propane, 81
propellants, aerosol, 58, 75
propylbenzene, 78
propylene glycol, 115
prototype, 165

prototype designs, 223
pseudomonas pneumonia, 56
psychiatric disturbances, 93
psychosis, 81
public information, 224
pulmonary edema, 69
pulmonary function, 40, 59, 83
pulmonary hyper-reactivity, 30
pulmonary infection, 54
pulse, loss of, 95
pulse, loss of peripheral, 45
putty, 74, 75, 95
pyrene, 36
pyridino nitrogen compounds, 24
radiant heat, 172, 191, 212
radiant heat, to bake paint, 143
radiation, 84
radiation dose, from radon daughters, 16
radiation, natural, 7
radio, 117
radioactive compounds, 40
radioactive equilibrium, 15
radium-226, 14, 15
radon, 6, 14*, 84, 86, 127, 130
radon, and ventilation, 135
radon daughters (decay products), 6, 14, 84, 86
radon daughters, unattached, 149
radon, measurements in tight homes, 138
radon, rate of creation in soil, 15
radon, reduction of pathways, 139
radon, standards, 15, 17
rashes, 46, 124
reaction, delayed, 175
reaction, strength of, 174
reaction time, effect of CO on, 12
reactive gases, 110
readership, 3
reading newspaper, 126
recirculation, 135, 140
recirculated air, filtering, 149
recirculation, 188, 212
recirculation, Sunnyhill, 172
reclamation of heat, 187
recognizing health problems, 221
recovery time, from susceptibility, 94
recycled newspapers, 124
recycled paper, PCBs, 111
recycled water, 54, 128
red blood cells, and ozone, 30
red blood cells, changes, 31
red blood cells, destruction, 13
reducing use of volatiles, 221
reduction of ventilation, 129
rehabilitation, 94, 99, 215, 224
relative humidity, 52, 53
remodelling, 123
remote burner, 190
removal of combustion process, 146
removal of contamination, 145
removal of pollutant sources, 155
renovation cost, 222
replacement materials, 145
research, 98
research needs, 161
research program, 225
resin, 54
resin products, 73
resin solvents, 75
respirable suspended particulates, 36, 60*, 103, 106, 108
respiration, 126, 128, 131
respiration, diminished, 49
respiratory ailments, 90, 124
respiratory allergy history, 45
respiratory collapse, 66
respiratory disease, 158
respiratory disease, as risk group, 92
respiratory disease, childhood, 87
respiratory disease, chronic, 91
respiratory illness, 24, 38, 40, 44
respiratory impairment, from nitrogen dioxide, 24
respiratory irritants, 91
respiratory paralysis, 13
respiratory symptoms, chronic, 93
restaurant, smoke in, 37
resuspension of dust, 60
retina, effects from methanol, 81
retrofitting houses, 130, 147
rhinorrhea, 95
rhizopus nigricans, 53
rhodotorula, 53
riboflavin deficiency, 91
rice-bran oil, PCBs, 82
rigid foam, 77
risk groups, 86
road dust, 61

Rochester study, 138, 144
rock wool insulation, 60, 124
rodents, 60
ronnel (pesticide), 64
room deodorants, 70
rubber, 110
rubber products, 42
rubber solvents, 75
rules, house, 200
runny nose, 46, 174
rush hour peak, 140
rust paint, 178
rusts, 52, 53
safety, 97
safety, margin of, 217
salivation, 66, 69, 94
sanctuary, 173, 196
scrubbing of air, 149
sea spray, 7
sealants, 73, 74, 151
sealers, 95, 120*, 128
sealing building envelope, 220
sealing compounds, 157
sealing pollutants, 155, 169
seasonal cycles, 140
seasonal variations, 53
secular equilibrium, 15
self-cleaning ovens, 117
seminars, 165
sensitivity, spreading of, 46
sensitization, 86, 88
sensitization, to TDI, 83
sensitized persons, 88
sensitizing chemicals, 67, 82, 85
sensitizing chemicals and allergy, 97
sensory perception, 22
separation from pollutants, 170
separation of activities, 195
separation of areas, 212
serum alpha antitrypsin, 91
sewage treatment, 56
sheathing, styrofoam, 177
sheathing, tar-impregnated, 177
shelf lining, asbestos, 33
shellac, 121
shift work, 88, 91
shingles, 178
shivering, 56
shoe polish, 116
short-circuiting hazards, 223
shortness of breath, 40, 45,
 46, 54, 59
shower heads, 57
shower heads, legionella in, 56
showers, 14, 71
shutters, insulating, 189, 204
sign, entrance, 200
silaceous dusts, 61, 62
silica, 61
silicates, 33
silicone caulking, 178
silvex, 67
sinks, 18C
sinus congestion, 46, 93
sinusitis, 66, 174
sizing agents, 110
skin cells, 50
skin irritation, 44, 62, 81,
 82, 93, 111
skin rashes, 59
skin rashes, with cellulose, 124
sludge, in humidifier, 119
smell, loss of sense of, 13
smelting operations, 60
smog, 29, 30, 63, 68, 133
smokers, 13, 38, 84, 87
smokers, as high risk group, 40
smokers, numbers of, 37, 40
smokers, numbers of in Canada, 40
smokers, venting of, 153, 159
smoking and children, 40
smoking, as a risk factor, 40, 90,
 91, 158
smoking, energy cost of, 159
smoking, policy, 172, 200
smoking, reduction, 154
smuts, 52
sneezing, 27, 46, 69, 70, 174
sneezing, and infection, 55
sniff test, 174
sodium bicarbonate, 151
sodium hydroxide, 121
sodium hypochlorite, 70, 115
sodium lauryl sulphate, in carpet
 shampoo, 115
softeners, in fabrics, 110
softwood, 69, 177
softwood, avoiding, 184
soil drench (chlordane), 65
soil excavation, and legionella, 56

---

soil gases, 7, 14, 15, 113, 127, 209
soil release treatment, of fabrics, 110
solar heat, 172
solar heat, active, 190
solar heat, air, 221
solar heat, passive, 189, 212
solvent glues, 73
solvents, 6, 72, 73, 75, 81, 110, 126
somnolence, 22
sore throat, 46, 94
sores not healing, 124
sound transmission, 184
source removal, 145, 155
sources of pollutants, 101
space heaters, 60
spackling compounds, 33, 61
spalling of brick, 131
spasms, of gastrocnemius, 45
special needs, 218
speech disturbance, 13
spin finish agents, 111
spinning residues, 110
sponge rubber, 96
spores, mould, 52
spores, removal of, 54
spot venting, 153
spray humidifiers, 119*
spreading phenomenon, 88, 94
spruce, 177
stabilizers, 76, 82
stagnation of water, 119
stainless steel, 180
stainless steel chimney liners, 102
stains, 75
standards, indoor air quality, 160, 217
standing water, 54, 55, 85, 119
starch, laundry, 115
stearoic oxide, 111
steel, 177, 213
steel, enamelled, 178
steel, framing, 212, 213
steel, galvanized, 180
steel, stainless, 180
stereo sets, 117
steroids, 36
stiff shoulders, 124
still-birth, 82
stock yards, 68
stone, mould on, 53
storage, external, 222
storage, of volatiles, 219
stress load, 86, 94, 158
structural damage, 131
studs, metal, 185
stuffiness, 138, 174
stuffiness, nasal, 95
stupor, 80
styrene, 75, 80, 82
styrene butadiene elastomer, 120
styrofoam insulation, 125, 128
styrofoam, 177, 213
sub-slab ducts, 64
subcontractors, 211
submarine environment, 53
submarine atmosphere, 149
substitute materials, 145
substitution, 169
substitution, by subcontractor, 208
sulphates, 60, 87
sulphates, organic, 26
sulphide oxidase activity, 28
sulphur, 26, 36, 60
sulphur dioxide, 6, 26*, 84, 103, 106, 108, 109, 111, 113, 114
sulphur dioxide, and Vitamin A, 32
sulphur dioxide, deposition, 142
sulphur dioxide, outdoor levels, 28
sulphur dioxide, standards, 27
sulphur tetroxide, 26
sulphur trioxide, 26
sulphuric acid, 26
sunlight, 20, 26, 95, 111, 189
super-sealed homes, 219
supervision, 201, 207
surface coatings, 110
surfaces, deterioration of, 57
surrogate indicators, 136
susceptibility, 93
susceptibility, chemical, (see chemical susceptibility)
susceptibility, during illness, 88
susceptibility, of smokers, 40
susceptibility, spreading of, 46, 83, 88, 94
susceptibility, variation over time, 88
susceptibility, individual variation, 90

susceptibility, to natural gas, 104
susceptible populations, 13
suspected carcinogen, 80
suspended particulates, 60*, 85, 114
suspension, 58
swelling, 95
swelling eyelids, 82
swelling of mucous membranes, 45
swimming pools, 70
swollen hands, 94
sylene, 78
symptoms, chronic, 175
syncope, 22, 70
synergistic effects, 83, 98
synthetic alcohol, 96
synthetic carpet, removal, 145
synthetic curtains, in sunlight, 131
synthetic fabrics, 95
synthetic fiber particles, 50, 51
synthetic foams, 112
synthetic materials, 157
synthetic polymer, heat resistance, 131
synthetic polymers, in floor polishes, 116
T lymphocytes, 96
T-cell depression, 47, 96
T-cell production, 67
tactile senations, 111
talcs, 60
tape, polyethylene, 205
tar, 36, 177
task venting, 153
taste, loss of sense of, 13
tea, 61
tearing, 71
television, emissions from, 117, 126
temperature, for legionnella, 57
temperature, increased, 131*
tempering intake air, 187
tempering of day/night temperatures, 189
teratogenic effects, 82
termite control, 64, 65
termiticide, 66
terpenes, 78, 182
test room, 174
testing facilities, 224
testing of materials, 173, 216
testing, interpretation, 176
tetany, 45
tetrabromoethanol, 111
tetrachloroethylene, 72, 74, 77, 81, 82
tetrahydrofuran (THF), 73, 81
tetramethylthiuram, 76
textile dyes, PCBs in, 74
textiles, formaldehyde in, 42
thermal stress, 110
thermally polluted water, 56
thermophilic actinomycetes fungi, 119
thresholds, 90, 161
throat irritation, 44, 46, 59, 69, 81
throwaway filters, 150
tightening of houses, 1, 47, 84, 86, 105, 129, 130*, 144, 158-160, 219, 220
tile, ceramic, 180, 198
timber, deterioration, 52
time spent indoors, 5, 98
tin, 77
tiredness, 93
titanium dioxide (pigment), 110, 120
toaster, 117
tobacco smoking, 9, 18, 159
tobacco smoke, 36, 60, 61, 70, 72, 75, 84, 219
tobacco smoke, adsorption, 142
tobacco smoke, and ventilation, 135, 153
tobacco smoke, mainstream, 36, 37*
tobacco smoke, sidestream, 37*
toilet bowl cleaners, 71
tolerance, to chlorine, 70
tolerance, to foods, 95
tolerance, to ozone, 31
toluene di-isocyanate, 76, 77, 82, 83
toluene di-isocyanate, in automobile interiors, 112
toluene, 36, 72, 77, 78, 80, 81, 116
toluene, from motors, 117
total complement, 96
total load, 94
total pollutant load, 1
total stress load, 86, 127
total suspended particulates (TSP), 60*, 61, 63, 85, 87, 109
total suspended particulates, standards, 61
toxic effects, 86

toxicity, 8
trace metals, 36
tracheal mucous velocity, 59
traffic arteries, 62
transformers, PCBs in, 74
treating pollutants, 152, 156, 169
tremors, 49, 94
tribromochloroethanol, 111
trichlorethane, 77
trichloroethylene, 72, 75, 77, 80
trichloroisocyanuric acid, 115
trichoderma viride, 53
trichoderma, 53
trimellitates, 76
trimethyl benzenes, 72
trimethylcyclohexane, 112
tumorogens, 38
turpentine, 96, 116, 120, 121
ultraviolet light, 57, 143, 172
ultraviolet absorbers, in
 fabrics, 110
unattached radon daughters, 149
unconsciousness, 49, 82
undecane, 78
under-ventilation, 136
unexpected problems, 201
unfinished wood, 142
unknowns, medical, 98
unmasking, 93
unsaturated aldehydes, 45
unsealed insulation, 219
unsealed particleboard, 219
unvented heaters, 106
uraniferous geology, 16
uranium-238, 14
uranium mining, 15
urea-formaldehyde foam insulation, 1,
 35, 42, 44, 45, 46, 75, 86, 87, 88,
 95, 124, 128, 145, 157
urea-formaldehyde resin, 42, 44
urea-formaldehyde resin, in
 fabrics, 110
urethane, 95, 123
urethane floor finish, 179
vacuum, central, 51, 170, 197
vacuum cleaner, 117
vacuum motor, 51
vacuum piping, 197
vacuuming, 51, 60, 148
vanadium, in aerosol, 115
vaporizers, 58
vapour barrier, 172, 205, 212
vapour barrier, attachment, 201
vapour barrier, careful sealing,
 213, 221
vapour barrier, loosening of
 seals, 207
vapour barrier, plastic, 95, 179
varnish, 75, 76, 83, 121
varnish remover, 76, 116
vegetable dust, 62
vegetable oils in paints, 120
vegetable resins, 120
vent fans, 170
vented combustion appliances, 146
vented cupboards, 194
ventilating systems, 55
ventilation, 8
ventilation, and radon, 17
ventilation, at the source, 156
ventilation, cost, 222
ventilation, decreased, 57, 84, 129,
 130*, 140, 155, 158-160
ventilation, deliberate, 221
ventilation, effects of
 pollutants, 139
ventilation, efficiency, 137
ventilation, for gassing out, 143
ventilation, increased, 135*, 155
ventilation, of hobbies, 126
ventilation, of tobacco smoke, 41
ventilation, shutdown, 136
venting, 183
venting, at the source, 153
venting, deliberate, 186
venting, of appliances, 118, 212,
 213, 221
venting, Sunnyhill, 170
ventricular fibrillation, 12
vents, brick, 186
vents, intake, 186
vents, wall, Sunnyhill, 170
vertigo, 47
video display terminals, 118
vigilance, 11
vinegar, 71
vinyl chloride, 58, 76, 81, 82, 111
vinyl chloride, from aerosols, 115
vinyl flooring, 179
vinyl plastic, 76

vinyl windows, 95
vinyl, 95, 143
vinyl, soft imitation leather, 112
vinylidene, 81
viral hepatitis, 89
viral infection, 68
virus, defence against, 87
viruses, 6, 7, 55*, 85
vision, blurred, 66
vision, dimming, 49
vision, effect of CO on, 12
vision, loss, 13
visual acuity, 30, 31
visual fields, 31
vitamin A, 32
vitamin A deficiency, 91
vitreous fibers, 6
voice loss, 70
volatiles, storage of, 116
volcanic eruption, 7
vomiting, 45, 46, 56, 64, 66, 95
vomiting and diarrhea, 56
waiting period, for gassing out, 143
wall, interior, 185
wall, surface, 69
wallboard, 47, 60
wallboard, fungicide in, 95
wallboard, PCBs in, 111
wallpaper, 26, 52, 69, 74, 95, 142
wallpaper, cellulosic,
 absorption, 142
warning devices, 154, 156
waste oil, 75
water repellancy, 110
water taps, 56
water vapour, 7, 36, 50, 126, 131
watery eyes, 124
wax solvents, 75
waxes, 73
waxes, PCBs in, 74
waxing compounds, 58, 148
weakness of muscles, 81
weakness, 66, 81, 93, 121, 124
weeping tiles, 14
weight loss, 56
well water, 14
wetting agents, in fabrics, 110
wheezing, 95
wick changes, kerosene heater, 106
widespread chemical susceptibility,
 46, 84, 93
windows, 170
windows, installation, 202
windows, openings, 209
windows, spacing, 189
windows, ventilation, 135
wires, steel, 204
wiring, plastic-coated, 132
withdrawal symptoms, 93
wood dust, 61, 62
wood filler, 75
wood finishes, 75
wood preservatives, 76, 95
wood preservatives, in furniture
 polish, 116
wood smoke, 70, 136, 155
wood smoke, second-hand, 127
wood stove, 18, 109*, 127
wood-burning, 109
wool, 69
wool, in dust, 50
working level, 15
workshop products, 58
xylene, xylenes, 72, 75, 77, 80
yawning, 174
yeasts, 53
zeolites, 60
zinc, 104

POOR

QUALITY

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